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(54) Title: VACCINES FOR ACTINOBACILLUS PLEUROPNEUMONIAE

(57) Abstract

Novel vaccines for use against *Actinobacillus pleuropneumoniae* are disclosed. The vaccines contain at least one *A. pleuropneumoniae* transferrin binding protein and/or one *A. pleuropneumoniae* cytolysin and/or one *A. pleuropneumoniae* APP4. Also disclosed are DNA sequences encoding these proteins, vectors including these sequences and host cells transformed with these vectors. The vaccines can be used to treat or prevent porcine respiratory infections.

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VACCINES FOR ACTINOBACILLUS PLEUROPNEUMONIAETechnical Field

10 The instant invention relates generally to the prevention of disease in swine. More particularly, the present invention relates to subunit vaccines for *Actinobacillus pleuropneumoniae*.

Background

15 *Actinobacillus* (formerly *Haemophilus*) *pleuropneumoniae* is a highly infectious porcine respiratory tract pathogen that causes porcine pleuropneumonia. Infected animals develop acute fibrinous pneumonia which leads to death or chronic lung lesions and reduced growth rates. Infection is 20 transmitted by contact or aerosol and the morbidity in susceptible groups can approach 100%. Persistence of the pathogen in clinically healthy pigs also poses a constant threat of transmitting disease to previously uninfected herds.

25 The rapid onset and severity of the disease often causes losses before antibiotic therapy can become effective. Presently available vaccines are generally composed of chemically inactivated bacteria combined with oil adjuvants. However, whole cell bacterins and surface 30 protein extracts often contain immunosuppressive components which make pigs more susceptible to infection. Furthermore, these vaccines may reduce mortality but do not reduce the number of chronic carriers in a herd.

35 There are at least 12 recognized serotypes of *A. pleuropneumoniae* with the most common in North America

-2-

being serotypes 1, 5 and 7. Differences among serotypes generally coincide with variations in the electrophoretic mobility of outer membrane proteins and enzymes thus indicating a clonal origin of isolates from the same 5 serotype. This antigenic variety has made the development of a successful vaccination strategy difficult. Protection after parenteral immunization with a killed bacterin or cell free extract is generally serotype specific and does not prevent chronic or latent 10 infection. Higgins, R., et al., *Can. Vet. J.* (1985) 26:86-89; MacInnes, J.I. and Rosendal, S., *Infect. Immun.* (1987) 55:1626-1634. Thus, it would be useful to develop vaccines which protect against both death and chronicity and do not have immunosuppressive properties. One method 15 by which this may be accomplished is to develop subunit vaccines composed of specific proteins in pure or semi-pure form.

*A. pleuropneumoniae* strains produce several cytolysins. See, e.g. Rycroft, A.N., et al., *J. Gen. Microbiol.* (1991) 137:561-568 (describing a 120 kDa cytolysin from *A. pleuropneumoniae*); Chang, Y.F., et al., *DNA* (1989) 8:635-647 (describing a cytolysin isolated from *A. pleuropneumoniae* serotype 5); Kamp, E.M., et al., *Abstr. CRWAD* (1990) 1990:270 (describing the presence of 25 103, 105 and 120 kDa cytolysins in *A. pleuropneumoniae* strains) and Welch, R.A., *Mol. Microbiol.* (1991) 5:521-528 (reviewing cytolysins of gram negative bacteria including cytolysins from *A. pleuropneumoniae*). One of these cytolysins appears to be homologous to the alpha-hemolysin of *E. coli* and another to the leukotoxin of *Pasteurella haemolytica*. Welch, R.A., *Mol. Microbiol.* (1991) 5:521-528. These proteins have a molecular mass of approximately 105 kDa and are protective in mouse and pig animal models against challenge with the homologous 30 serotype. However, cross-serotype protection is limited 35

-3-

at best (Higgins, R., et al., *Can. J. Vet.* (1985) 26:86-89; MacInnes, J.I., et al., *Infect. Immun.* (1987) 55:1626-1634. The genes for two of these proteins have been cloned and expressed in *E. coli* and their nucleotide sequence determined. Chang, Y.F., et al., *J. Bacteriol.* (1991) 173:5151-5158 (describing the nucleotide sequence for an *A. pleuropneumoniae* serotype 5 cytolysin); and Frey, J., et al., *Infect. Immun.* (1991) 59:3026-3032 (describing the nucleotide sequence for an *A. pleuropneumoniae* serotype 1 cytolysin).

Transferrins are serum glycoproteins that function to transport iron from the intestine where it is absorbed, and liver, where it is stored, to other tissues of the body. Cell surface receptors bind ferrotransferrin (transferrin with iron) and the complex enters the cell by endocytosis. *A. pleuropneumoniae*, under iron restricted growth conditions, can use porcine transferrin as its sole iron source, but it cannot utilize bovine or human transferrin (Gonzalez, G.C., et al., *Mol. Microbiol.* (1990) 4:1173-1179; Morton, D.J., and Williams, P., *J. Gen. Microbiol.* (1990) 136:927-933). The ability of other microorganisms to bind and utilize transferrin as a sole iron source as well as the correlation between virulence and the ability to scavenge iron from the host has been shown (Archibald, F.S., and DeVoe, I.W., *FEMS Microbiol. Lett.* (1979) 6:159-162; Archibald, F.S., and DeVoe, I.W., *Infect. Immun.* (1980) 27:322-334; Herrington, D.A., and Sparling, F.P., *Infect. Immun.* (1985) 48:248-251; Weinberg, E.D., *Microbiol. Rev.* (1978) 42:45-66).

It has been found that *A. pleuropneumoniae* possesses several outer membrane proteins which are expressed only under iron limiting growth conditions (Deneer, H.G., and Potter, A.A., *Infect. Immun.* (1989) 57:798-804). Three of these proteins have been isolated

from *A. pleuropneumoniae* serotypes 1, 2 and 7 using affinity chromatography. These proteins have molecular masses of 105, 76 and 56 kDa. (Gonzalez, G.C., et al., *Mol. Microbiol.* (1990) 4:1173-1179). The 105 and 56 kDa 5 proteins have been designated porcine transferrin binding protein 1 (pTfBP1) and porcine transferrin binding protein 2 (pTfBP2), respectively. (Gonzalez, G.C., et al., *Mol. Microbiol.* (1990) 4:1173-1179). At least one of these proteins has been shown to bind porcine 10 transferrin but not transferrin from other species (Gonzalez, G.C., et al., *Mol. Microbiol.* (1990) 4:1173-1179). It is likely that one of these proteins, either alone or in combination with other iron regulated outer membrane proteins, is involved in the transport of iron. 15 The protective capacity of these proteins has not heretofore been demonstrated.

Disclosure of the Invention

20 The instant invention is based on the discovery of novel subunit antigens from *A. pleuropneumoniae* which show protective capability in pigs.

Accordingly, in one embodiment, the subject invention is directed to a vaccine composition comprising a pharmaceutically acceptable vehicle and a subunit 25 antigen composition. The subunit antigen composition includes at least one amino acid sequence substantially homologous and functionally equivalent to an immunogenic polypeptide of an *Actinobacillus pleuropneumoniae* protein or an immunogenic fragment thereof. The immunogenic protein is selected from the group consisting of 30 *Actinobacillus pleuropneumoniae* transferrin binding protein, *Actinobacillus pleuropneumoniae* cytolysin and *Actinobacillus pleuropneumoniae* APP4.

In other embodiments, the instant invention is 35 directed to a nucleotide sequences encoding

*Actinobacillus pleuropneumoniae* transferrin binding proteins and nucleotide sequences encoding *Actinobacillus pleuropneumoniae* APP4 proteins, or proteins substantially homologous and functionally equivalent thereto.

5 In yet other embodiments, the subject invention is directed to DNA constructs comprising an expression cassette comprised of:

10 (a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* transferrin binding protein; and

15 (b) control sequences that are operably linked to the coding sequence whereby the coding sequence can be transcribed and translated in a host cell, and at least one of the control sequences is heterologous to the coding sequence.

In another embodiment, the subject invention is directed to a DNA construct comprising an expression cassette comprised of:

20 (a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* cytolysin; and

25 (b) control sequences that are operably linked to the coding sequence whereby the coding sequence can be transcribed and translated in a host cell, and at least one of the control sequences is heterologous to said coding sequence.

In still another embodiment, the invention is directed to a DNA construct comprising an expression cassette comprised of:

30 (a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* APP4; and

35 (b) control sequences that are operably linked to the coding sequence whereby the coding sequence can be transcribed and translated in a host cell, and at least

one of the control sequences is heterologous to the coding sequence.

5 In still further embodiments, the instant invention is directed to expression cassettes comprising the DNA constructs, host cells transformed with these expression cassettes, and methods of recombinantly producing the subject *Actinobacillus pleuropneumoniae* proteins.

10 In another embodiment, the subject invention is directed to methods of treating or preventing pneumonia in swine comprising administering to the swine a therapeutically effective amount of a vaccine composition as described above.

15 In still other embodiments, the invention is directed to isolated and purified *Actinobacillus pleuropneumoniae* serotype 7 60 kDa transferrin binding protein, serotype 5 62 kDa transferrin binding protein, serotype 1 65 kDa transferrin binding protein and serotypes 1 and 5 APP4.

20 These and other embodiments of the present invention will readily occur to those of ordinary skill in the art in view of the disclosure herein.

#### Brief Description of the Figures

25 Figure 1 depicts the nucleotide sequence and deduced amino acid sequence of *A. pleuropneumoniae* serotype 7 60 kDa transferrin binding protein as well as the nucleotide sequence for the flanking regions.

30 Figure 2 shows the nucleotide sequence and deduced amino acid sequence of *A. pleuropneumoniae* serotype 1 65 kDa transferrin binding protein as well as the nucleotide sequence for the flanking regions.

35 Figure 3 is a comparison of the amino acid sequences of *A. pleuropneumoniae* serotype 7 60 kDa transferrin binding protein (designated "TF205" therein)

and the *A. pleuropneumoniae* serotype 1 65 kDa transferrin binding protein (designated "TF37" therein). Dots indicate positions of identity.

Figure 4 shows the partial nucleotide sequence 5 of *A. pleuropneumoniae* serotype 7, 103 kDa cytolysin. The *Bgl*II site is the fusion point between the vector pGH432 lacI and the *A. pleuropneumoniae* derived sequence.

Figure 5 shows restriction endonuclease 10 cleavage maps of *A. pleuropneumoniae* serotype 7 cytolysin clones. The *cyA* region contains the structural gene for the cytolysin while *cyC* codes for an activator protein.

Figure 6 shows restriction endonuclease 15 cleavage maps for recombinant plasmids coding for *A. pleuropneumoniae* serotype 1 antigens. 6.1 = rAPP4, 6.2 = pTF37/E1. The heavy line indicates the vector sequence and the coordinates are 0.01 Kb.

Figure 7 shows a physical map and the 20 translational activity of plasmid pTF205/E1 and its deletion derivative, pTF205/E2. (A) The thick line represents DNA of the cloning vehicle (pGH433); tac indicates the location of the tac promoter, and the asterisk indicates stop codons in all three reading frames. The horizontal arrow indicates the location and 25 direction of transcription of the encoded protein; as indicated, this DNA fragment was also used as a probe.

(B) Depiction of an SDS gel of the IPTG induced aggregate 30 proteins produced by pTF205/E1 (lane 1) and pTF205/E2 (lane 2); the molecular weight standards (lane 3) are phosphorylase b (97,400), bovine serum albumin (66.20), ovalbumin (45,000), and carbonic anhydrase (31,000).

Figure 8 shows the mean ELISA titers (log) from 35 serum collected from pigs prior to vaccination with fractions from the hot saline extracts from Example 1, at day 24 and day 34 after vaccination. Mean values were

calculated for each vaccine group. The background level of 2.5-3.0 is normal for *Actinobacillus* free pigs.

Figure 9 shows the mean clinical scores of pigs given fractions from the hot saline extracts described in 5 Example 1. Data for the first three days post challenge are shown. Clinical scores range from 0-4 with 4 indicating death.

Figure 10 depicts the mean body temperature of pigs given fractions from the hot saline extracts 10 described in Example 1. Data for the first three days post challenge are shown. The values presented are degrees centigrade above 39°C.

Figure 11 depicts the mean lung scores of pigs given fractions from the hot saline extracts described in 15 Example 1. Lungs were removed at necropsy and scored for the number and size of *Porcine Haemophilus* Pleuropneumonia lesions. Results are presented as percent of lung area.

Figure 12 shows the means of clinical response 20 (12A) and body temperature (12B) of pigs challenged with *A. pleuropneumoniae* serotype 7 in trial 1 of Example 6. The numbers on top of the bars represent the number of animals from which the values were obtained.

Figure 13 shows the means of clinical response 25 (13A) and body temperature (13B) of pigs challenged with *A. pleuropneumoniae* serotype 7 in trial 2 of Example 6. The numbers on top of the bars represent the number of animals from which the values were obtained.

Figure 14 shows the nucleotide sequence of the 30 flanking regions of the repeats on  $\lambda$ CY76/5. *cytA* marks the position of the *cytA* gene, and the sequence at the *Xba*I site and upstream is identical to that described by Chang, Y.F., et al., *DNA* (1989) 8:635-647.

Figure 15 depicts the nucleotide sequence of 35 the inverted repeats of Figure 14 located on either end

of the direct repeats. Complementary bases are connected with a vertical dash.

Figure 16 depicts the nucleotide sequence of the *Bam*HI-*Bgl*III fragment of  $\lambda$ CY76 $\Delta$ 1/1. *Bam*HI, *Kpn*I, and *Bgl*III indicate the position of the restriction enzyme sites. The position and direction of the open reading frame is indicated by "MET" and "'''". "SD" marks the Shine-Dalgarno consensus sequence. The ends of the repeat are comprised of 26 bp long inverted repeats also emphasized by bold print.

#### Detailed Description

The practice of the present invention will employ, unless otherwise indicated, conventional techniques of molecular biology, microbiology, virology, recombinant DNA technology, and immunology, which are within the skill of the art. Such techniques are explained fully in the literature. See, e.g., Sambrook, Fritsch & Maniatis, Molecular Cloning: A Laboratory Manual, Second Edition (1989); DNA Cloning, Vols. I and II (D.N. Glover ed. 1985); Oligonucleotide Synthesis (M.J. Gait ed. 1984); Nucleic Acid Hybridization (B.D. Hames & S.J. Higgins eds. 1984); Animal Cell Culture (R.K. Freshney ed. 1986); Immobilized Cells and Enzymes (IRL press, 1986); Perbal, B., A Practical Guide to Molecular Cloning (1984); the series, Methods In Enzymology (S. Colowick and N. Kaplan eds., Academic Press, Inc.); and Handbook of Experimental Immunology, Vols. I-IV (D.M. Weir and C.C. Blackwell eds., 1986, Blackwell Scientific Publications).

All patents, patent applications and publications cited herein, whether supra or infra, are hereby incorporated by reference in their entirety.

**A. Definitions**

In describing the present invention, the following terms will be employed, and are intended to be defined as indicated below.

5 An "antigen" refers to a molecule containing one or more epitopes that will stimulate a host's immune system to make a humoral and/or cellular antigen-specific response. The term is also used interchangeably with "immunogen."

10 By "subunit antigen" is meant an antigen entity separate and discrete from a whole bacterium (live or killed). Thus, an antigen contained in a cell free extract would constitute a "subunit antigen" as would a substantially purified antigen.

15 A "hapten" is a molecule containing one or more epitopes that does not stimulate a host's immune system to make a humoral or cellular response unless linked to a carrier.

20 The term "epitope" refers to the site on an antigen or hapten to which a specific antibody molecule binds. The term is also used interchangeably with "antigenic determinant" or "antigenic determinant site."

25 An "immunological response" to a composition or vaccine is the development in the host of a cellular and/or antibody-mediated immune response to the composition or vaccine of interest. Usually, such a response consists of the subject producing antibodies, B cells, helper T cells, suppressor T cells, and/or cytotoxic T cells directed specifically to an antigen or antigens 30 included in the composition or vaccine of interest.

35 The terms "immunogenic polypeptide" and "immunogenic amino acid sequence" refer to a polypeptide or amino acid sequence, respectively, which elicits antibodies that neutralize bacterial infectivity, and/or mediate antibody-complement or antibody dependent cell

-11-

cytotoxicity to provide protection of an immunized host. An "immunogenic polypeptide" as used herein, includes the full length (or near full length) sequence of the desired *A. pleuropneumoniae* protein or an immunogenic fragment thereof. By "immunogenic fragment" is meant a fragment of a polypeptide which includes one or more epitopes and thus elicits antibodies that neutralize bacterial infectivity, and/or mediate antibody-complement or antibody dependent cell cytotoxicity to provide protection of an immunized host. Such fragments will usually be at least about 5 amino acids in length, and preferably at least about 10 to 15 amino acids in length. There is no critical upper limit to the length of the fragment, which could comprise nearly the full length of the protein sequence, or even a fusion protein comprising fragments of two or more of the *A. pleuropneumoniae* subunit antigens.

The term "polypeptide" is used in its broadest sense, i.e., any polymer of amino acids (dipeptide or greater) linked through peptide bonds. Thus, the term "polypeptide" includes proteins, oligopeptides, protein fragments, analogs, muteins, fusion proteins and the like.

"Native" proteins or polypeptides refer to proteins or polypeptides recovered from a source occurring in nature. Thus, the term "native transferrin binding protein", "native cytolysin" or "native APP4" would include naturally occurring transferrin binding protein, cytolysin or APP4, respectively, and fragments of these proteins. "Recombinant" polypeptides refer to polypeptides produced by recombinant DNA techniques; i.e., produced from cells transformed by an exogenous DNA construct encoding the desired polypeptide. "Synthetic" polypeptides are those prepared by chemical synthesis.

-12-

A "replicon" is any genetic element (e.g., plasmid, chromosome, virus) that functions as an autonomous unit of DNA replication *in vivo*; i.e., capable of replication under its own control.

5 A "vector" is a replicon, such as a plasmid, phage, or cosmid, to which another DNA segment may be attached so as to bring about the replication of the attached segment.

10 A "double-stranded DNA molecule" refers to the polymeric form of deoxyribonucleotides (bases adenine, guanine, thymine, or cytosine) in a double-stranded helix, both relaxed and supercoiled. This term refers only to the primary and secondary structure of the molecule, and does not limit it to any particular 15 tertiary forms. Thus, this term includes double-stranded DNA found, *inter alia*, in linear DNA molecules (e.g., restriction fragments), viruses, plasmids, and chromosomes. In discussing the structure of particular double-stranded DNA molecules, sequences may be described 20 herein according to the normal convention of giving only the sequence in the 5' to 3' direction along the nontranscribed strand of DNA (i.e., the strand having the sequence homologous to the mRNA).

25 A DNA "coding sequence" or a "nucleotide sequence encoding" a particular protein, is a DNA sequence which is transcribed and translated into a polypeptide *in vivo* when placed under the control of appropriate regulatory sequences. The boundaries of the coding sequence are determined by a start codon at the 5' 30 (amino) terminus and a translation stop codon at the 3' (carboxy) terminus. A coding sequence can include, but is not limited to, prokaryotic sequences, cDNA from eucaryotic mRNA, genomic DNA sequences from eucaryotic (e.g., mammalian) DNA, and even synthetic DNA sequences.

A transcription termination sequence will usually be located 3' to the coding sequence.

A "promoter sequence" is a DNA regulatory region capable of binding RNA polymerase in a cell and 5 initiating transcription of a downstream (3' direction) coding sequence. For purposes of defining the present invention, the promoter sequence is bound at the 3' terminus by the translation start codon (ATG) of a coding sequence and extends upstream (5' direction) to include 10 the minimum number of bases or elements necessary to initiate transcription at levels detectable above background. Within the promoter sequence will be found a transcription initiation site (conveniently defined by mapping with nuclease S1), as well as protein binding 15 domains (consensus sequences) responsible for the binding of RNA polymerase. Eucaryotic promoters will often, but not always, contain "TATA" boxes and "CAT" boxes. Procaryotic promoters contain Shine-Dalgarno sequences in addition to the -10 and -35 consensus sequences.

20 DNA "control sequences" refers collectively to promoter sequences, ribosome binding sites, polyadenylation signals, transcription termination sequences, upstream regulatory domains, enhancers, and the like, which collectively provide for the 25 transcription and translation of a coding sequence in a host cell.

"Operably linked" refers to an arrangement of elements wherein the components so described are configured so as to perform their usual function. Thus, 30 control sequences operably linked to a coding sequence are capable of effecting the expression of the coding sequence. The control sequences need not be contiguous with the coding sequence, so long as they function to direct the expression thereof. Thus, for example, 35 intervening untranslated yet transcribed sequences can be

present between a promoter sequence and the coding sequence and the promoter sequence can still be considered "operably linked" to the coding sequence.

A control sequence "directs the transcription" 5 of a coding sequence in a cell when RNA polymerase will bind the promoter sequence and transcribe the coding sequence into mRNA, which is then translated into the polypeptide encoded by the coding sequence.

A "host cell" is a cell which has been 10 transformed, or is capable of transformation, by an exogenous DNA sequence.

A cell has been "transformed" by exogenous DNA when such exogenous DNA has been introduced inside the cell membrane. Exogenous DNA may or may not be 15 integrated (covalently linked) into chromosomal DNA making up the genome of the cell. In prokaryotes and yeasts, for example, the exogenous DNA may be maintained on an episomal element, such as a plasmid. With respect to eucaryotic cells, a stably transformed cell is one in 20 which the exogenous DNA has become integrated into the chromosome so that it is inherited by daughter cells through chromosome replication. This stability is demonstrated by the ability of the eucaryotic cell to establish cell lines or clones comprised of a population 25 of daughter cells containing the exogenous DNA.

A "clone" is a population of cells derived from a single cell or common ancestor by mitosis. A "cell line" is a clone of a primary cell that is capable of stable growth *in vitro* for many generations.

30 Two DNA or polypeptide sequences are "substantially homologous" when at least about 80% (preferably at least about 90%, and most preferably at least about 95%) of the nucleotides or amino acids match over a defined length of the molecule. As used herein, 35 substantially homologous also refers to sequences showing

identity to the specified DNA or polypeptide sequence. DNA sequences that are substantially homologous can be identified in a Southern hybridization experiment under, for example, stringent conditions, as defined for that 5 particular system. Defining appropriate hybridization conditions is within the skill of the art. See, e.g., Sambrook et al., *supra*; DNA Cloning, vols I & II, *supra*; Nucleic Acid Hybridization, *supra*.

10 The term "functionally equivalent" intends that the amino acid sequence of the subject protein is one that will elicit an immunological response, as defined above, equivalent to the specified *A. pleuropneumoniae* immunogenic polypeptide.

15 A "heterologous" region of a DNA construct is an identifiable segment of DNA within or attached to another DNA molecule that is not found in association with the other molecule in nature. Thus, when the heterologous region encodes a bacterial gene, the gene will usually be flanked by DNA that does not flank the 20 bacterial gene in the genome of the source bacteria. Another example of the heterologous coding sequence is a construct where the coding sequence itself is not found in nature (e.g., synthetic sequences having codons different from the native gene). Allelic variation or 25 naturally occurring mutational events do not give rise to a heterologous region of DNA, as used herein.

30 A composition containing A is "substantially free of" B when at least about 85% by weight of the total of A + B in the composition is A. Preferably, A comprises at least about 90% by weight of the total of A + B in the composition, more preferably at least about 95%, or even 99% by weight.

The term "treatment" as used herein refers to either (i) the prevention of infection or reinfection

-16-

(prophylaxis), or (ii) the reduction or elimination of symptoms of the disease of interest (therapy).

**B. General Methods**

5       Central to the instant invention is the discovery of certain *A. pleuropneumoniae* proteins able to elicit an immune response in an animal to which they are administered. The antigens, or immunogenic fragments thereof, are provided in subunit vaccine compositions and 10 thus problems inherent in prior vaccine compositions, such as localized and systemic side reactions, as well as the inability to protect against chronic disease, are avoided. The vaccine compositions can be used to treat or prevent *A. pleuropneumoniae* induced respiratory 15 diseases in swine such as porcine pleuropneumonia. The antigens or antibodies thereto can also be used as diagnostic reagents to detect the presence of *A. pleuropneumoniae* infection in a subject. Similarly, the genes encoding the subunit antigens can be cloned and 20 used to design probes for the detection of *A. pleuropneumoniae* in tissue samples as well as for the detection of homologous genes in other bacterial strains. The subunit antigens are conveniently produced by recombinant techniques, as described herein. The 25 proteins of interest are produced in high amounts in transformants, do not require extensive purification or processing, and do not cause lesions at the injection site or other ill effects.

It has now been found that *A. pleuropneumoniae* 30 possesses proteins able to bind transferrin. Specifically, two transferrin binding proteins have been identified in cell free extracts from *A. pleuropneumoniae* serotype 7. These proteins have molecular masses of approximately 60 kDa and 100 kDa, respectively, as 35 determined by SDS PAGE. The 100 kDa protein is seen only

-17-

in cells grown under iron restriction and appears to be present in substantial amounts in the outer membrane. The 60 kDa protein is detectable in whole cell lysates and culture supernatants from bacteria grown under iron restricted conditions. This protein is not seen in outer membranes prepared by SDS solubilization. The protein does not appear to be expressed under conditions of heat, ethanol, or oxidative stress. The 60 kDa protein, when separated by nondenaturing PAGE, binds alkaline phosphatase labeled porcine transferrin and exhibits species-specific binding in competitive ELISAs. Congo Red and hemin are able to bind this protein, thereby inhibiting the transferrin binding activity. Southern and Western blot analysis shows that this, or a related protein is also likely present in *A. pleuropneumoniae* serotypes 2, 3, 4, 8, 9, 10 and 11 in addition to serotype 7. A functionally related protein is present in serotypes 1, 5 and 12. The 60 kDa transferrin binding protein is effective in protecting pigs against *A. pleuropneumoniae* infections. The presence of this protein in culture supernatants and its absence from purified outer membranes indicates that it is different from the iron regulated outer membrane proteins previously described by Deneer and Potter (Deneer, H.G., and Potter, A.A., *Infect. Immun.* (1989) 57:798-804).

The gene encoding the *A. pleuropneumoniae* serotype 7 60 kDa transferrin binding protein has been isolated and the sequence is depicted in Figure 1. The nucleotide sequence including the structural gene and flanking regions consists of approximately 2696 base pairs. The open reading frame codes for a protein having approximately 547 amino acids. The putative amino acid sequence of the 60 kDa protein is also depicted in Figure 1. The recombinantly produced protein is able

-18-

to protect pigs from subsequent challenge with *A. pleuropneumoniae*.

The gene encoding an *A. pleuropneumoniae* serotype 5 transferrin binding protein has also been 5 identified and cloned. This gene was cloned by screening an *A. pleuropneumoniae* serotype 5 genomic library with DNA probes from a plasmid which encodes the serotype 7 60 kDa transferrin binding protein (thus suggesting at least partial homology to this protein). When transformed into 10 *E. coli* HB101, the recombinant plasmid expressing the serotype 5 transferrin binding protein gene produced a polypeptide of approximately 62 kDa which reacted with convalescent serum from an *A. pleuropneumoniae* serotype 5-infected pig. The serotype 5 recombinant transferrin 15 binding protein is also able to protect pigs from subsequent challenge with *A. pleuropneumoniae*, as described further below.

*A. pleuropneumoniae* serotype 1 has also been found to possess a protein which shows 58.3% homology 20 with the serotype 7 60 kDa transferrin binding protein (Figure 3). The nucleotide sequence and deduced amino acid sequence of the serotype 1 transferrin binding protein is shown in Figure 2. The nucleotide sequence including the structural gene and flanking sequences 25 consists of approximately 1903 base pairs. The open reading frame codes for a protein having about 593 amino acids. This protein has a molecular mass of approximately 65 kDa, as determined by SDS PAGE.

As is apparent, the transferrin binding 30 proteins appear to perform the same function (iron scavenging) and exhibit homology between serotypes. Vaccination with one serotype does not always provide cross-protection against another serotype. However, when these transferrin binding proteins are combined with

other subunit antigens, as described below, cross-protection against clinical symptoms becomes possible.

It has also been found that *A. pleuropneumoniae* serotype 7 possesses at least one cytolysin with protective capability. This cytolysin has a molecular mass of approximately 103 kDa, as determined by SDS-PAGE. The gene for this cytolysin has been cloned and a partial nucleotide sequence determined (Figure 4). The partial sequence shows identity with part of the sequence determined for a cytolysin isolated from *A. pleuropneumoniae* serotype 5 (Chang, Y.F., et al., *DNA* (1989) 8:635-647). A carboxy-terminal fragment of this cytolysin, containing 70% of the protein, has been found protective in an experimental pig model.

*A. pleuropneumoniae* serotypes also possess another protective protein, designated APP4, having a molecular mass of approximately 60 kDa. The genes encoding the proteins from serotypes 1 and 5, respectively, have been cloned. A restriction endonuclease cleavage map for a recombinant plasmid coding for recombinant *A. pleuropneumoniae* serotype 1 APP4 (rAPP4) is shown in Figure 6.1. The gene coding a serotype 5 homolog of APP4 has been cloned from a library screened with DNA probes from the above plasmid. Both the serotype 5 and serotype 1 APP4 proteins afford protection in pigs from a subsequent challenge with *A. pleuropneumoniae*. Other APP4 proteins useful in the present vaccines include immunogenic APP4 polypeptides from additional *A. pleuropneumoniae* serotypes.

The described proteins, or immunogenic fragments thereof, or cell free extracts including the same, can be used either alone or in combination vaccine compositions. Such compositions can contain any combination of the described antigens, such as one or more *A. pleuropneumoniae* transferrin binding proteins

and/or one or more *A. pleuropneumoniae* cytolysins and/or one or more *A. pleuropneumoniae* APP4s. Combination vaccines containing antigens from more than one serotype will provide broad spectrum protection. However, since 5 it has been found that there is little cross-protection against heterologous serotypes when single antigens are used, for best results, serotype 7 antigens should be used for protection against *A. pleuropneumoniae* serotype 7 infections, serotype 1 antigens for protection against 10 serotype 1 infections, serotype 5 antigens for protection against serotype 5 infections, and so on. Furthermore, based on genetic and antigenic differences of the 60 kDa proteins in strains studied, as well as the presence of two different cytolysins in certain serotypes (described 15 further below), vaccines containing more than one of the cytolysins as well as the serotype specific 60 kDa proteins are particularly attractive for providing cross-protection against clinical symptoms.

If synthetic or recombinant proteins are 20 employed, the subunit antigen can be a single polypeptide encoding several epitopes from just one of the *A. pleuropneumoniae* proteins or several epitopes from more than one of the proteins (e.g., a fusion protein). Synthetic and recombinant subunit antigens can also 25 comprise two or more discrete polypeptides encoding different epitopes.

The above described antigens can be produced by a variety of methods. Specifically, the antigens can be isolated directly from *A. pleuropneumoniae*, as described 30 below. Alternatively, the antigens can be recombinantly produced as described herein. The proteins can also be synthesized, based on the described amino acid sequences, using techniques well known in the art.

For example, the antigens can be isolated from 35 bacteria which express the same. This is generally

-21-

accomplished by first preparing a crude extract which lacks cellular components and several extraneous proteins. The desired antigens can then be further purified i.e. by column chromatography, HPLC,

5 immunoadsorbent techniques or other conventional methods well known in the art.

Purification of the above proteins as described herein permits the sequencing of the same by any of the various methods known to those skilled in the art. For 10 example, the amino acid sequences of the subject proteins can be determined from the purified proteins by repetitive cycles of Edman degradation, followed by amino acid analysis by HPLC. Other methods of amino acid sequencing are also known in the art. Furthermore, 15 fragments of the proteins can be tested for biological activity and active fragments, as described above, used in compositions in lieu of the entire protein.

Once the amino acid sequences are determined, oligonucleotide probes which contain the codons for a 20 portion of the determined amino acid sequences can be prepared and used to screen DNA libraries for genes encoding the subject proteins. The basic strategies for preparing oligonucleotide probes and DNA libraries, as well as their screening by nucleic acid hybridization, 25 are well known to those of ordinary skill in the art. See, e.g., DNA Cloning: Vol. I, *supra*; Nucleic Acid Hybridization, *supra*; Oligonucleotide Synthesis, *supra*; T. Maniatis *et al.*, *supra*.

First, a DNA library is prepared. The library 30 can consist of genomic DNA from *A. pleuropneumoniae*. Once the library is constructed, oligonucleotides to probe the library are prepared and used to isolate the gene encoding the desired protein. The oligonucleotides are synthesized by any appropriate method. The 35 particular nucleotide sequences selected are chosen so as

to correspond to the codons encoding a known amino acid sequence from the desired protein. Since the genetic code is degenerate, it will often be necessary to synthesize several oligonucleotides to cover all, or a reasonable number, of the possible nucleotide sequences which encode a particular region of the protein. Thus, it is generally preferred in selecting a region upon which to base the probes, that the region not contain amino acids whose codons are highly degenerate. In certain circumstances, one of skill in the art may find it desirable to prepare probes that are fairly long, and/or encompass regions of the amino acid sequence which would have a high degree of redundancy in corresponding nucleic acid sequences, particularly if this lengthy and/or redundant region is highly characteristic of the protein of interest. It may also be desirable to use two probes (or sets of probes), each to different regions of the gene, in a single hybridization experiment. Automated oligonucleotide synthesis has made the preparation of large families of probes relatively straightforward. While the exact length of the probe employed is not critical, generally it is recognized in the art that probes from about 14 to about 20 base pairs are usually effective. Longer probes of about 25 to about 60 base pairs are also used.

The selected oligonucleotide probes are labeled with a marker, such as a radionucleotide or biotin using standard procedures. The labeled set of probes is then used in the screening step, which consists of allowing the single-stranded probe to hybridize to isolated ssDNA from the library, according to standard techniques. Either stringent or permissive hybridization conditions could be appropriate, depending upon several factors, such as the length of the probe and whether the probe is derived from the same species as the library, or an

evolutionarily close or distant species. The selection of the appropriate conditions is within the skill of the art. See, generally, Nucleic Acid hybridization, *supra*. The basic requirement is that hybridization conditions be 5 of sufficient stringency so that selective hybridization occurs; i.e., hybridization is due to a sufficient degree of nucleic acid homology (e.g., at least about 65%), as opposed to nonspecific binding. Once a clone from the screened library has been identified by positive 10 hybridization, it can be confirmed by restriction enzyme analysis and DNA sequencing that the particular insert contains a gene coding for the desired protein.

Alternatively, DNA sequences encoding the proteins of interest can be prepared synthetically rather 15 than cloned. The DNA sequence can be designed with the appropriate codons for the particular amino acid sequence. In general, one will select preferred codons for the intended host if the sequence will be used for expression. The complete sequence is assembled from 20 overlapping oligonucleotides prepared by standard methods and assembled into a complete coding sequence. See, e.g., Edge (1981) *Nature* 292:756; Nambair et al. (1984) *Science* 223:1299; Jay et al. (1984) *J. Biol. Chem.* 259:6311.

Once coding sequences for the desired proteins have been prepared or isolated, they can be cloned into any suitable vector or replicon. Numerous cloning vectors are known to those of skill in the art, and the selection of an appropriate cloning vector is a matter of 25 choice. Examples of recombinant DNA vectors for cloning and host cells which they can transform include the bacteriophage  $\lambda$  (*E. coli*), pBR322 (*E. coli*), pACYC177 (*E. coli*), pKT230 (gram-negative bacteria), pGV1106 (gram-negative bacteria), pLAFR1 (gram-negative 30 bacteria), pME290 (non-*E. coli* gram-negative bacteria),

pHV14 (*E. coli* and *Bacillus subtilis*), pBD9 (*Bacillus*), pIJ61 (*Streptomyces*), pUC6 (*Streptomyces*), YIp5 (*Saccharomyces*), YCp19 (*Saccharomyces*) and bovine papilloma virus (mammalian cells). See, generally, DNA Cloning: Vols. I & II, *supra*; T. Maniatis et al., *supra*; B. Perbal, *supra*.

The gene can be placed under the control of a promoter, ribosome binding site (for bacterial expression) and, optionally, an operator (collectively referred to herein as "control" elements), so that the DNA sequence encoding the desired protein is transcribed into RNA in the host cell transformed by a vector containing this expression construction. The coding sequence may or may not contain a signal peptide or leader sequence. The subunit antigens of the present invention can be expressed using, for example, the *E. coli* tac promoter or the protein A gene (*spa*) promoter and signal sequence. Signal sequences can be removed by the bacterial host in post-translational processing.

See, e.g., U.S. Patent Nos. 4,431,739; 4,425,437; 4,338,397.

In addition to control sequences, it may be desirable to add regulatory sequences which allow for regulation of the expression of the protein sequences relative to the growth of the host cell. Regulatory sequences are known to those of skill in the art, and examples include those which cause the expression of a gene to be turned on or off in response to a chemical or physical stimulus, including the presence of a regulatory compound. Other types of regulatory elements may also be present in the vector, for example, enhancer sequences.

An expression vector is constructed so that the particular coding sequence is located in the vector with the appropriate regulatory sequences, the positioning and orientation of the coding sequence with respect to the

control sequences being such that the coding sequence is transcribed under the "control" of the control sequences (i.e., RNA polymerase which binds to the DNA molecule at the control sequences transcribes the coding sequence).  
5 Modification of the sequences encoding the particular antigen of interest may be desirable to achieve this end. For example, in some cases it may be necessary to modify the sequence so that it may be attached to the control sequences with the appropriate orientation; i.e., to  
10 maintain the reading frame. The control sequences and other regulatory sequences may be ligated to the coding sequence prior to insertion into a vector, such as the cloning vectors described above. Alternatively, the coding sequence can be cloned directly into an expression  
15 vector which already contains the control sequences and an appropriate restriction site.

In some cases, it may be desirable to add sequences which cause the secretion of the polypeptide from the host organism, with subsequent cleavage of the  
20 secretory signal. It may also be desirable to produce mutants or analogs of the antigens of interest. Mutants or analogs may be prepared by the deletion of a portion of the sequence encoding the protein, by insertion of a sequence, and/or by substitution of one or more  
25 nucleotides within the sequence. Techniques for modifying nucleotide sequences, such as site-directed mutagenesis, are well known to those skilled in the art. See, e.g., T. Maniatis et al., *supra*; DNA Cloning, Vols. I and II, *supra*; Nucleic Acid Hybridization, *supra*.

30 A number of prokaryotic expression vectors are known in the art. See, e.g., U.S. Patent Nos. 4,440,859; 4,436,815; 4,431,740; 4,431,739; 4,428,941; 4,425,437; 4,418,149; 4,411,994; 4,366,246; 4,342,832; see also U.K. Patent Applications GB 2,121,054; GB 2,008,123; GB  
35 2,007,675; and European Patent Application 103,395.

Yeast expression vectors are also known in the art. See, e.g., U.S. Patent Nos. 4,446,235; 4,443,539; 4,430,428; see also European Patent Applications 103,409; 100,561; 96,491.

5         Depending on the expression system and host selected, the proteins of the present invention are produced by growing host cells transformed by an expression vector described above under conditions whereby the protein of interest is expressed. The protein is then  
10         isolated from the host cells and purified. If the expression system secretes the protein into growth media, the protein can be purified directly from the media. If the protein is not secreted, it is isolated from cell lysates. The selection of the appropriate growth conditions and recovery methods are within the skill of the  
15         art.

An alternative method to identify proteins of the present invention is by constructing gene libraries, using the resulting clones to transform *E. coli* and  
20         pooling and screening individual colonies using polyclonal serum or monoclonal antibodies to the desired antigen.

The proteins of the present invention may also be produced by chemical synthesis such as solid phase  
25         peptide synthesis, using known amino acid sequences or amino acid sequences derived from the DNA sequence of the genes of interest. Such methods are known to those skilled in the art. Chemical synthesis of peptides may be preferable if a small fragment of the antigen in  
30         question is capable of raising an immunological response in the subject of interest.

The proteins of the present invention or their fragments can be used to produce antibodies, both polyclonal and monoclonal. If polyclonal antibodies are  
35         desired, a selected mammal, (e.g., mouse, rabbit, goat,

horse, etc.) is immunized with an antigen of the present invention, or its fragment, or a mutated antigen. Serum from the immunized animal is collected and treated according to known procedures. If serum containing 5 polyclonal antibodies is used, the polyclonal antibodies can be purified by immunoaffinity chromatography, using known procedures.

Monoclonal antibodies to the proteins of the present invention, and to the fragments thereof, can also 10 be readily produced by one skilled in the art. The general methodology for making monoclonal antibodies by using hybridoma technology is well known. Immortal antibody-producing cell lines can be created by cell fusion, and also by other techniques such as direct 15 transformation of B lymphocytes with oncogenic DNA, or transfection with Epstein-Barr virus. See, e.g., M. Schreier et al., Hybridoma Techniques (1980); Hammerling et al., Monoclonal Antibodies and T-cell Hybridomas (1981); Kennett et al., Monoclonal Antibodies (1980); see 20 also U.S. Patent Nos. 4,341,761; 4,399,121; 4,427,783; 4,444,887; 4,452,570; 4,466,917; 4,472,500, 4,491,632; and 4,493,890. Panels of monoclonal antibodies produced 25 against the antigen of interest, or fragment thereof, can be screened for various properties; i.e., for isotype, epitope, affinity, etc. Monoclonal antibodies are useful in purification, using immunoaffinity techniques, of the individual antigens which they are directed against.

Animals can be immunized with the compositions 30 of the present invention by administration of the protein of interest, or a fragment thereof, or an analog thereof. If the fragment or analog of the protein is used, it will include the amino acid sequence of an epitope which interacts with the immune system to immunize the animal 35 to that and structurally similar epitopes. If

combinations of the described antigens are used, the antigens can be administered together or provided as separate entities.

Prior to immunization, it may be desirable to 5 increase the immunogenicity of the particular protein, or an analog of the protein, or particularly fragments of the protein. This can be accomplished in any one of several ways known to those of skill in the art. For example, the antigenic peptide may be administered linked 10 to a carrier. For example, a fragment may be conjugated with a macromolecular carrier. Suitable carriers are typically large, slowly metabolized macromolecules such as: proteins; polysaccharides, such as sepharose, agarose, cellulose, cellulose beads and the like; 15 polymeric amino acids such as polyglutamic acid, polylysine, and the like; amino acid copolymers; and inactive virus particles. Especially useful protein substrates are serum albumins, keyhole limpet hemocyanin, immunoglobulin molecules, thyroglobulin, ovalbumin, and 20 other proteins well known to those skilled in the art.

The protein substrates may be used in their native form or their functional group content may be modified by, for example, succinylation of lysine residues or reaction with Cys-thiolactone. A sulfhydryl 25 group may also be incorporated into the carrier (or antigen) by, for example, reaction of amino functions with 2-iminothiolane or the N-hydroxysuccinimide ester of 3-(4-dithiopyridyl propionate. Suitable carriers may also be modified to incorporate spacer arms (such as 30 hexamethylene diamine or other bifunctional molecules of similar size) for attachment of peptides.

Other suitable carriers for the proteins of the present invention include VP6 polypeptides of rotaviruses, or functional fragments thereof, as 35 disclosed in U.S. Patent No. 5,071,651, and incorporated

-29-

herein by reference. Also useful is a fusion product of a viral protein and the subject immunogens made by methods disclosed in U.S. Patent No. 4,722,840. Still other suitable carriers include cells, such as 5 lymphocytes, since presentation in this form mimics the natural mode of presentation in the subject, which gives rise to the immunized state. Alternatively, the proteins of the present invention may be coupled to erythrocytes, preferably the subject's own erythrocytes. Methods of 10 coupling peptides to proteins or cells are known to those of skill in the art.

The novel proteins of the instant invention can also be administered via a carrier virus which expresses the same. Carrier viruses which will find use with the 15 instant invention include but are not limited to the vaccinia and other pox viruses, adenovirus, and herpes virus. By way of example, vaccinia virus recombinants expressing the novel proteins can be constructed as follows. The DNA encoding the particular protein is 20 first inserted into an appropriate vector so that it is adjacent to a vaccinia promoter and flanking vaccinia DNA sequences, such as the sequence encoding thymidine kinase (TK). This vector is then used to transfect cells which are simultaneously infected with vaccinia. Homologous 25 recombination serves to insert the vaccinia promoter plus the gene encoding the instant protein into the viral genome. The resulting TK recombinant can be selected by culturing the cells in the presence of 5-bromodeoxyuridine and picking viral plaques resistant 30 thereto.

It is also possible to immunize a subject with a protein of the present invention, or a protective fragment thereof, or an analog thereof, which is administered alone, or mixed with a pharmaceutically 35 acceptable vehicle or excipient. Typically, vaccines are

prepared as injectables, either as liquid solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid vehicles prior to injection may also be prepared. The preparation may also be emulsified 5 or the active ingredient encapsulated in liposome vehicles. The active immunogenic ingredient is often mixed with vehicles containing excipients which are pharmaceutically acceptable and compatible with the active ingredient. Suitable vehicles are, for example, 10 water, saline, dextrose, glycerol, ethanol, or the like, and combinations thereof. In addition, if desired, the vehicle may contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents, or adjuvants which enhance the effectiveness of 15 the vaccine. Adjuvants may include for example, muramyl dipeptides, avridine, aluminum hydroxide, oils, saponins and other substances known in the art. Actual methods of preparing such dosage forms are known, or will be apparent, to those skilled in the art. See, e.g., Remington's 20 Pharmaceutical Sciences, Mack Publishing Company, Easton, Pennsylvania, 15th edition, 1975. The composition or formulation to be administered will, in any event, contain a quantity of the protein adequate to achieve the desired immunized state in the individual being treated.

25 Additional vaccine formulations which are suitable for other modes of administration include suppositories and, in some cases, aerosol, intranasal, oral formulations, and sustained release formulations. For suppositories, the vehicle composition will include 30 traditional binders and carriers, such as, polyalkaline glyccols, or triglycerides. Such suppositories may be formed from mixtures containing the active ingredient in the range of about 0.5% to about 10% (w/w), preferably about 1% to about 2%. Oral vehicles include such 35 normally employed excipients as, for example,

pharmaceutical grades of mannitol, lactose, starch, magnesium, stearate, sodium saccharin cellulose, magnesium carbonate, and the like. These oral vaccine compositions may be taken in the form of solutions, 5 suspensions, tablets, pills, capsules, sustained release formulations, or powders, and contain from about 10% to about 95% of the active ingredient, preferably about 25% to about 70%.

Intranasal formulations will usually include 10 vehicles that neither cause irritation to the nasal mucosa nor significantly disturb ciliary function. Diluents such as water, aqueous saline or other known substances can be employed with the subject invention. The nasal formulations may also contain preservatives 15 such as, but not limited to, chlorobutanol and benzalkonium chloride. A surfactant may be present to enhance absorption of the subject proteins by the nasal mucosa.

Controlled or sustained release formulations 20 are made by incorporating the protein into carriers or vehicles such as liposomes, nonresorbable impermeable polymers such as ethylenevinyl acetate copolymers and Hytrel® copolymers, swellable polymers such as hydrogels, or resorbable polymers such as collagen and certain 25 polyacids or polyesters such as those used to make resorbable sutures. The proteins can also be delivered using implanted mini-pumps, well known in the art.

Furthermore, the proteins (or complexes 30 thereof) may be formulated into vaccine compositions in either neutral or salt forms. Pharmaceutically acceptable salts include the acid addition salts (formed with the free amino groups of the active polypeptides) and which are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such 35 organic acids as acetic, oxalic, tartaric, mandelic, and

the like. Salts formed from free carboxyl groups may also be derived from inorganic bases such as, for example, sodium, potassium, ammonium, calcium, or ferric hydroxides, and such organic bases as isopropylamine, 5 trimethylamine, 2-ethylamino ethanol, histidine, procaine, and the like.

To immunize a subject, the polypeptide of interest, or an immunologically active fragment thereof, is administered parenterally, usually by intramuscular 10 injection in an appropriate vehicle. Other modes of administration, however, such as subcutaneous, intravenous injection and intranasal delivery, are also acceptable. Injectable vaccine formulations will contain an effective amount of the active ingredient in a 15 vehicle, the exact amount being readily determined by one skilled in the art. The active ingredient may typically range from about 1% to about 95% (w/w) of the composition, or even higher or lower if appropriate. The quantity to be administered depends on the animal to be 20 treated, the capacity of the animal's immune system to synthesize antibodies, and the degree of protection desired. With the present vaccine formulations, 5  $\mu$ g to 1 mg of active ingredient, more preferably 10  $\mu$ g to 500  $\mu$ g, of active ingredient, should be adequate to raise an 25 immunological response when a dose of 1 to 2 ml of vaccine per animal is administered. Other effective dosages can be readily established by one of ordinary skill in the art through routine trials establishing dose response curves. The subject is immunized by 30 administration of the particular antigen or fragment thereof, or analog thereof, in at least one dose, and preferably two doses. Moreover, the animal may be administered as many doses as is required to maintain a state of immunity to pneumonia.

An alternative route of administration involves gene therapy or nucleic acid immunization. Thus, nucleotide sequences (and accompanying regulatory elements) encoding the subject proteins can be 5 administered directly to a subject for *in vivo* translation thereof. Alternatively, gene transfer can be accomplished by transfecting the subject's cells or tissues *ex vivo* and reintroducing the transformed material into the host. DNA can be directly introduced 10 into the host organism, i.e. by injection (see International Publication No. WO/90/11092; and Wolff et al., Science (1990) 247:1465-1468). Liposome-mediated gene transfer can also be accomplished using known methods. See, e.g., Hazinski et al., Am. J. Respir. Cell 15 Mol. Biol. (1991) 4:206-209; Brigham et al., Am. J. Med. Sci. (1989) 298:278-281; Canonico et al., Clin. Res. (1991) 39:219A; and Nabel et al., Science (1990) 249:1285-1288. Targeting agents, such as antibodies directed against surface antigens expressed on specific 20 cell types, can be covalently conjugated to the liposomal surface so that the nucleic acid can be delivered to specific tissues and cells susceptible to *A. pleuropneumoniae* infection.

Below are examples of specific embodiments for 25 carrying out the present invention. The examples are offered for illustrative purposes only, and are not intended to limit the scope of the present invention in any way.

30 Deposits of Strains Useful in Practicing the Invention

A deposit of biologically pure cultures of the following strains was made with the American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland. The accession number indicated was assigned after 35 successful viability testing, and the requisite fees were

-34-

paid. Access to said cultures will be available during pendency of the patent application to one determined by the Commissioner to be entitled thereto under 37 CFR 1.14 and 35 USC 122. All restriction on availability of said 5 cultures to the public will be irrevocably removed upon the granting of a patent based upon the application. Moreover, the designated deposits will be maintained for a period of thirty (30) years from the date of deposit, or for five (5) years after the last request for the 10 deposit; or for the enforceable life of the U.S. patent, whichever is longer. Should a culture become nonviable or be inadvertently destroyed, or, in the case of plasmid-containing strains, lose its plasmid, it will be replaced with a viable culture(s) of the same taxonomic 15 description.

These deposits are provided merely as a convenience to those of skill in the art, and are not an admission that a deposit is required under 35 USC §112. The nucleic acid sequences of these plasmids, as well as 20 the amino sequences of the polypeptides encoded thereby, are incorporated herein by reference and are controlling in the event of any conflict with the description herein. A license may be required to make, use, or sell the deposited materials, and no such license is hereby 25 granted.

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-35-

	<u>Strain</u>	<u>Deposit Date</u>	<u>ATCC No.</u>
	pTF37/E1 (in <i>E. coli</i> )	10/19/91	68823
	pTF205/E1 (in <i>E. coli</i> )	10/19/91	68821
5	pTF205/E2 (in <i>E. coli</i> )	10/19/91	68822
	pTF213/E6 (in <i>E. coli</i> )	10/8/92	69084
	pCY76/503 (in <i>E. coli</i> )	10/19/91	68820
	p#4-213-84 (in <i>E. coli</i> )	10/8/92	69082
	prAPP4 (in <i>E. coli</i> )	4/7/92	68955
10	<i>A. pleuropneumoniae</i> serotype 7 strain AP37	10/19/91	55242

15                   C. Experimental

Materials and Methods

Enzymes were purchased from commercial sources, and used according to the manufacturers' directions. Radionucleotides and nitrocellulose filters were also purchased from commercial sources.

20                   In the cloning of DNA fragments, except where noted, all DNA manipulations were done according to standard procedures. See Sambrook et al., *supra*.

25                   Restriction enzymes, *T*<sub>4</sub> DNA ligase, *E. coli*, DNA polymerase I, Klenow fragment, and other biological reagents were purchased from commercial suppliers and used according to the manufacturers' directions. Double stranded DNA fragments were separated on agarose gels.

30                   Bacterial Strains, Plasmids and Media

35                   *A. pleuropneumoniae* serotype 7 strain AP205 was a Nebraska clinical isolate obtained from M.L. Chepok, Modern Veterinary Products, Omaha, Nebraska. *A. pleuropneumoniae* serotype 1 strain AP37, *A. pleuropneumoniae* serotype 5 strain AP213 and *A.*

-36-

5 *A. pleuropneumoniae* serotype 7 strain AP76, were isolated from the lungs of diseased pigs given to the Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. The other  
10 *A. pleuropneumoniae* strains were field isolates from herds in Saskatchewan. The *E. coli* strain HB101 (*hsdM*, *hsdR*, *recA*) was used in all transformations using plasmid DNA. *E. coli* strains NM538 (*supF*, *hsdR*) and NM539 (*supF*, *hsdR*, *P2cox*) served as hosts for the bacteriophage  $\lambda$  library. The plasmids pGH432 and pGH433 are expression vectors containing a tac promoter, a translational start site with restriction enzyme sites allowing ligation in all three reading frames followed by stop codons in all reading frames.

15 15 *A. pleuropneumoniae* strains were grown on PPLO medium (Difco Laboratories, Detroit, MI) supplemented with 1% IsoVitalex (BBL Microbiology Systems, Becton Dickinson & Co., Cockeysville, MD 21030). Plate cultures were incubated in a CO<sub>2</sub>-enriched (5%) atmosphere at 37°C.  
20 Liquid cultures were grown with continuous shaking at 37°C without CO<sub>2</sub> enrichment.

25 25 Iron restriction was obtained by adding 2,2 dipyridyl to a final concentration of 100  $\mu$ mol. Heat stress was induced by transferring cultures to 45°C for 2 hours. Ethanol stress was exerted by the addition of 10% (vol/vol final concentration) of absolute ethanol to cultures in mid log phase. Oxidative stress was induced by the addition of 1% (vol/vol final concentration) of 30% H<sub>2</sub>O<sub>2</sub> to the cultures. *E. coli* transformants were  
30 grown in Luria medium (Maniatis, T., et al., Molecular Cloning: A Laboratory Manual (1982) Cold Spring Harbor Laboratory, Cold Spring Harbor, NY) supplemented with ampicillin (100 mg/l).

Preparation and Analysis of Culture Supernatants, Outer Membranes and Protein Aggregates.

Culture supernatants were mixed with two volumes of absolute ethanol and kept at -20°C for 1 h.

5 Precipitates were recovered by centrifugation and resuspended in water. Outer membranes were prepared by sarkosyl solubilization as previously described (Deneer, H.G., and Potter, A.A., *Infect. Immun.* (1989) 57:798-804). For the preparation of protein aggregates, broth 10 cultures (50 ml) in mid log phase (OD<sub>660</sub> of 0.6) were induced by the addition of 1 mmol isopropylthiogalactoside (IPTG; final concentration). After 2 hours of vigorous shaking at 37°C, cells were harvested by centrifugation, resuspended in 2 ml of 25% sucrose, 15 50 mmol Tris/HCl buffer pH 8, and frozen at -70°C. Lysis was achieved by the addition of 5 µg of lysozyme in 250 mmol Tris/HCl buffer pH 8 (5 min on ice), addition of 10 ml detergent mix (5 parts 20 mmol Tris/HCl buffer pH 8 (5 min on ice), addition of 10 ml detergent mix (5 parts 20 mmol Tris/HCl buffer pH 7.4, 300 mmol NaCl, 2% deoxycholic acid, 2% NP-40, and 4 parts of 100 mmol Tris/HCl buffer pH 8, 50 mmol ethylenediamine tetraacetic acid, 2% Triton X-100), and by sonication. Protein 20 aggregates were harvested by centrifugation for 30 min at 15,000 g. Aggregate protein was resuspended in H<sub>2</sub>O to a concentration of 5-10 mg/ml and solubilized by the addition of an equal volume of 7 molar guanidine 25 hydrochloride.

Proteins were analyzed by discontinuous sodium 30 dodecylsulfate polyacrylamide gel electrophoresis (SDS PAGE) according to the method of Laemmli (Laemmli, M.K., *Nature* (1970) 227:680-685). The protein concentration was determined using a modified Lowry protein assay which prevents reaggregation of the protein. Bovine serum 35 albumin (Pierce Chemical Co., Rockford, IL) was used as a

-38-

standard. Briefly, samples were taken up in 0.5 ml of 1% sodium dodecyl sulfate (SDS), 0.1 mol NaOH, and 1.5 ml of 0.2 mol Na<sub>2</sub>CO<sub>3</sub>, 0.07 mol NaKC<sub>4</sub>H<sub>4</sub>O<sub>6</sub>·4H<sub>2</sub>O, 0.1 mol NaOH, 0.001 mol CuSO<sub>4</sub>·5H<sub>2</sub>O were added. After 15 min incubation at 5 20°C, 0.15 ml of phenol reagent, diluted 1:2 with distilled water, was added. Samples were incubated at 55°C for 15 min, and the optical density at 660 nm was determined.

Electrophoretic transfer onto nitrocellulose 10 membranes was performed essentially as described by Towbin et al. (Towbin et al., Proc. Natl. Acad. Sci. U.S.A. (1979) 76:4350-4354). Nonspecific binding was blocked by incubation in 0.5% gelatine in washing buffer (150 mmol saline, 30 mmol Tris-HCl, 0.05% Triton-X100). 15 Antibody and alkaline phosphatase conjugate (Kirkegaard & Perry Laboratories, Inc., Gaithersburg, MD) were added in washing buffer, and each incubated for 1 h at room temperature. Blots were developed with a substrate containing 5-bromo-4-chloro-3-indolyl phosphate (BCIP) 20 and nitro blue tetrazolium (NBT); ImmunoSelect, BRL, Gaithersburg, MD) in 100 mmol Tris/HCl buffer pH 9.5, 50 mmol NaCl, 5 mmol MgCl<sub>2</sub>.

#### Preparation of Antisera

25 Convalescent serum was obtained as follows. Pigs were given 10<sup>3</sup> A. pleuropneumoniae intranasally and were challenged 2 weeks later with 2 LD50. Serum against the recombinant protein was raised in mice by intraperitoneal injection of 30 µg of solubilized 30 aggregate in complete Freund's adjuvant and a subcutaneous boost with 30 µg protein in incomplete Freund's adjuvant two weeks later.

Iron Compounds

Transferrins from different species were obtained commercially (porcine transferrin from The Binding Site, Birmingham, UK; human and bovine transferrin from Sigma Chemical Co.). Porcine transferrin was iron depleted as described by Mazurier and Spik (Mazurier, J., and G. Spik, *Biochim. Biophys. Acta* (1980) 629:399-408). The resulting porcine apotransferrin as well as the commercially obtained bovine and human apotransferrins were iron repleted as described by Herrington and Sparling (Herrington, D.A., and F.P. Sparling, *Infect. Immun.* (1985) 48:248-251).

Transferrin Binding Assays

To assess the possible transferrin binding ability of recombinant proteins, a Western blot-like transferrin binding assay was performed essentially as described by Morton and Williams (Morton, D.J., and P. Williams, *J. Gen. Microbiol.* (1990) 136:927-933). During the entire procedure the temperature was kept below 37°C. Blots were developed using biotinylated transferrin (Biotin-XX-NHS Ester Labeling Kit, Clontech Laboratories, Palo Alto, CA) coupled to streptavidin phosphatase and purified by gel filtration using a G-100 column. In order to determine species specificity of transferrin binding, a competitive ELISA was developed. ELISA plates (Immulon 2, Dynatech Laboratories, McLean, Virginia) were coated with 100 µl of porcine transferrin at a concentration of 100 µg/ml in carbonate buffer at 4°C over night. All subsequent steps were performed at room temperature. Plates were blocked with 0.5% gelatine in washing buffer. Solubilized protein at a concentration of approximately 5 µg/ml was incubated in washing buffer for 1 hour with an equal volume of serial two fold dilutions of porcine, bovine, and human transferrin.

Subsequently, 200  $\mu$ l of this solution were added to the coated and washed wells and incubated for one hour. The assay was developed using a mouse serum raised against the recombinant protein, an alkaline phosphatase labeled conjugate and p-nitrophenyl phosphate in 1 mol diethanolamine, pH 9.5, 5 mmol MgCl<sub>2</sub>, as substrate. The plates were read at 405 nm in a Biorad plate reader, and 50% inhibition values were determined for the various transferrins.

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EXAMPLESExample 1Fractionation of Hot Saline Extracts

Vaccination of pigs with cell free extracts reduces mortality following experimental challenge. However, the presence of an uncharacterized immunosuppressive component can interfere with the induction of protective immunity in a dose dependent fashion. Therefore, an attempt was made to remove this component by preparative isoelectrofocusing. Cell free extracts were prepared as follows. *Actinobacillus pleuropneumoniae* serotype 1 strain AP37 was grown to mid log phase in PPLO broth supplemented with Isovitallex and the bacteria harvested by pelleting cells by centrifugation at 8,000 x g for 15 minutes. Cells were resuspended in 1/10 volume of 0.85% sodium chloride and the mixture was shaken with glass beads at 60°C for 1 hour. Cells were removed by centrifugation as described above and the supernatant material filter sterilized. This material was dialyzed against distilled water to remove the sodium chloride, mixed with Biorad ampholytes (pH range 3-11) and loaded in a Rotafor isoelectrofocusing cell. The mixture was focused at 12 watts constant power for 4-6 hours. Fractions were pooled into four samples according

to pH as shown below. This material was used to vaccinate groups of 6 pigs as shown below.

5                   Group 1: Fraction A, pH = 10.4  
                  Group 2: Fraction B, pH = 6.1  
                  Group 3: Fraction C, pH = 5.2  
                  Group 4: Fraction D, pH = 2.4  
                  Group 5: Mixture, Fraction A-D  
                  Group 6: Same as Group 5.  
10                   Group 7: Placebo (no antigen)

15                   Marcol-52 was used as an adjuvant, and all pigs were boosted with the appropriate vaccine formulation after 3 weeks. After an additional week, all pigs were exposed to an aerosol of *Actinobacillus pleuropneumoniae* strain AP37 and clinical data plus body temperatures were recorded daily. In addition, serum samples collected at days 0, 21 and 34 of the trial were used to determine the serological response to vaccination by an enzyme linked 20 immunosorbent assay (ELISA). The results are summarized in Figures 8 through 11. Pigs in Groups 1, 4, 5 and 6 all had significantly increased ELISA titers compared to the control group while those in Group 2 and 3 were only marginally better. These results were reflected in the 25 mean clinical scores (Figure 9), mean temperatures (Figure 10) and mean lung scores (Figure 11). Clearly, those pigs which received Fraction D or the mixture of all four Fractions were protected against experimental challenge. Furthermore, it appeared that these vaccine 30 preparations reduced colonization of the lung, which can be a measure of chronicity.

35                   Each of the above fractions was analyzed by polyacrylamide gel electrophoresis and Western blotting using sera collected from each pig prior to challenge. Fractions A and B contained little protein but a

substantial quantity of lipopolysaccharide and lipoprotein. Fraction C contained a small quantity of protein, largely four components with molecular weights ranging from 100,000 to 14,000. Fraction D, which 5 exhibited the greatest protective capacity, had the largest quantity of protein and contained at least 22 different components. However, only 7 proteins were present in significant amounts. Western blots revealed the presence of four strongly reactive proteins in 10 Fractions C and D. These proteins had molecular weights of approximately 20 kDa, 40 kDa, 75 kDa and 100 kDa.

Example 2

Cloning of Genes Coding for  
Serotype 1 Protective Proteins

15 All restriction enzyme digests were done in T4 DNA polymerase buffer (Maniatis, T., et al., Molecular Cloning: A Laboratory Manual (1982) Cold Spring Harbor Laboratory, Cold Spring Harbor, NY) containing 1 mmol 20 dithiothreitol and 3 mmol spermidine.

A. *pleuropneumoniae* AP37 genomic DNA was prepared as previously described (Stauffer, G.V., et al., *Gene* (1981) 14:63-72) and partially digested with the restriction endonuclease *Sau*3AI. Fragments of 3000 to 8000 Bp were 25 isolated by sucrose density gradient centrifugation (Maniatis, *supra*) and ligated into pGH432 and pGH433 which had been digested with *Bam*HI and/or *Bgl*III. The ligated DNA was used to transform *E. coli* strain JM105. The colonies were transferred to nitrocellulose 30 membranes, induced with IPTG and screened for reaction with serum from pigs vaccinated with Fraction D of the hot saline extract (above). Three positive clones which expressed *Actinobacillus* proteins were selected for further study. The restriction endonuclease maps of the 35 three plasmids are shown in Figure 6. One clone, prAPP4

(Figure 6.1), codes for the serotype 1 APP4. Another clone (pTF37/E1, Figure 6.3) codes for a putative serotype 1 transferrin binding protein, based on homology with its serotype 7 homolog (see below and Figure 3).

5 The nucleotide sequence of the gene coding for this protein was determined using the chain termination method as described by Sanger, F., et al., *Proc. Natl. Acad. Sci. USA* (1977) 74:5463-5467. Nested deletions were prepared by exonuclease III treatment, and specific

10 primers were prepared using a Pharmacia Gene Assembler. Sequences were analyzed using the IBI/Pustell program and the Genbank network. The nucleotide sequence and deduced amino acid sequence are depicted in Figure 2.

15 Example 3

Cloning of *Actinobacillus pleuropneumoniae*  
Serotype 7 60 kDa Transferrin Binding Protein

As above, all restriction enzyme digests were done in T4 DNA polymerase buffer (Maniatis, *supra*) containing 1 mmol dithiothreitol and 3 mmol spermidine. Genomic DNA libraries of *A. pleuropneumoniae* serotype 7 strain AP205 were prepared as previously described (Stauffer, *supra*) and partially digested with the restriction endonuclease Sau3AI. Fragments of 1500 to

20 2500 Bp were isolated by sucrose density gradient centrifugation (Maniatis, *supra*) and ligated into pGH432 and pGH433. *E. coli* HB101 transformants were replicated onto nitrocellulose membranes, induced for 2 hours on plates containing 1 mM IPTG and screened for reaction

25 30 with serum from pigs infected with serotype 7 *A. pleuropneumoniae*. Positive transformants were replated, induced with IPTG and whole cell proteins were analyzed by Western blotting. A whole cell lysate of *A. pleuropneumoniae* grown under iron limiting conditions

35 was used as a control.

Of approximately 6000 transformants screened by immunoblotting, 22 reacted with convalescent serum and showed an immunoreactive band in the Western blot analysis. One transformant expressed a protein with the same electrophoretic mobility as an *A. pleuropneumoniae* polypeptide present only under iron limiting growth conditions. The plasmid present in this transformant was designated pTF205/E1 (Figure 7A). The recombinant polypeptide produced by this strain had a molecular weight of 60,000 (Figure 7B) and was produced as inclusion bodies, indicating that it was under the control of the tac promoter. Aggregated protein prepared from pTF205/E2 (a BamHI/BglII deletion derivative of the original plasmid) was used to immunize mice. The resulting serum reacted with a single polypeptide in the whole cell lysates and in culture supernatants from *A. pleuropneumoniae* serotype 7 strain AP205 grown under iron limiting conditions. Outer membranes prepared by sarkosyl solubilization (Deneer, H.G., and Potter, A.A., *Infect. Immun.* (1989) 57:798-804) of cells grown under iron limiting conditions did not react with the antiserum. Likewise, whole cell lysates, culture supernatants and outer membranes from cells grown in iron replete media did not react with the antibody.

The recombinant protein separated by non-reducing polyacrylamide gel electrophoresis was found to bind alkaline phosphatase-labeled porcine transferrin. This binding was shown to be species specific in a competitive ELISA, where the binding of the solubilized protein to iron replete porcine transferrin could be inhibited completely only by iron replete porcine transferrin. Porcine apotransferrin also inhibited binding, but a higher concentration was necessary. Using human and bovine iron-deplete and -replete transferrins, 50% inhibition could not be obtained even with

-45-

concentrations 40 times higher than the inhibitory dose for porcine transferrin. In addition, relatively high concentrations of both hemin and Congo Red could inhibit transferrin-binding of the 60 kDa protein, whereas 5 porcine hemoglobin, EDDA, dipyridyl, and ferric citrate failed to do so (Table 1).

10 Congo Red and hemin binding by *E. coli* transformants expressing this protein at low levels was detected by supplementing the ampicillin containing Luria agar with 1-10  $\mu$ mol IPTG and 0.003% Congo Red or 0.02% hemin.

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**Table 1**  
**Competitive ELISA Showing the Differences in Affinity of the**  
**Recombinant 60 kDa Protein Toward Transferrins of Various Species**

<u>Solid Phase Antigen</u>	<u>Competitive Substances<sup>1</sup></u>	<u>50% Inhibition Values<sup>2</sup> [<math>\mu</math>g/ml]</u>	<u>[<math>\mu</math>mol]</u>
	porcine	25 <sup>3</sup>	0.3
	porcine Tf	150	1.8
	human Tf/ATF	>1000 <sup>4</sup>	>12.5
	bovine Tf/ATF	>1000 <sup>4</sup>	>12.5
porcine transferrin (TF)	porcine Tf, NH <sub>2</sub> -terminus	20	0.5
	bovine hemin	4	6.0
	Congo Red	25	35.0

<sup>1</sup> Also tested and completely noninhibitory were porcine hemoglobin (14  $\mu$ mol), EDDA (100  $\mu$ mol, iron-saturated), Dipyridyl (100  $\mu$ mol, iron-saturated), and ferric citrate (10  $\mu$ mol).

<sup>2</sup> Inhibition values state the concentration of transferrin necessary in the preincubation step in order to obtain an inhibition of 50% in the reaction between recombinant protein and solid phase transferrin.

<sup>3</sup> The value varied between different experiments between 12.5 and 100  $\mu$ g/ml; however, the relative difference in inhibitory activity between the various substances was constant.

<sup>4</sup> This concentration had an inhibitory effect, but it was below 50%.

Chromosomal DNA was prepared from 27 different clinical isolates of *A. pleuropneumoniae* belonging to 6 different serotypes digested with the restriction endonucleases *Bgl*III and *Eco*RV, and separated on an agarose gel. This fragment was chosen because the functional activity of the deletion plasmid pTF205/E2 localized the position of the serotype 7 60 kDa gene upstream of the *Bgl*III site. A Southern blot analysis using the *Eco*RV/*Bgl*III fragment of pTF205/E1 as a probe detected a fragment identical in size in all of the above *A. pleuropneumoniae* serotype 2, 4 and 7 strains as well as in one serotype 3 strain. In contrast, none of the serotype 1 and 5 strains reacted with the probe. Neither did the *E. coli* HB101 and *Pasteurella haemolytica* controls.

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The nucleotide sequence of the gene coding for the transferrin binding protein was determined by the chain termination method as described in Example 2 and is shown in Figure 1.

#### Example 4

##### Cloning of *A. pleuropneumonia* Serotype 7 Cytolysin Gene

A recombinant plasmid containing the carboxy-terminal 70% of the 103 kDa serotype 7 cytolysin gene (*cytA*) was constructed as follows. A gene library of *A. pleuropneumoniae* serotype 7 strain AP76 was constructed in the phage vector  $\lambda$ 2001. Plaques were screened by hybridization using the *Pasteurella haemolytica* *lktA* gene as a probe (see Lo, R.Y.C., et al., *Infect. Immun.* (1987) 55:1987-1996 for a description of this gene). Positive plaques were purified and a 16 kb *Eco*RI fragment was subcloned into the plasmid vector pACYC184 (plasmid pCY76/5, Figure 5). A 3.5 kb *Bgl*III fragment from pCY76/5 was further subcloned into the *Bgl*III site of the expression vector pGH432 *lacI* which

provides a 5 amino acid leader peptide and an IPTG inducible promoter (pCY76/503, Figure 5). Nucleotide sequence analysis of the fusion site revealed sequence identity with the cytolysin from *A. pleuropneumoniae* serotype 5 (Figure 4; Chang, Y.F., et al., *DNA* (1989) 8:635-647). Further analysis of the *A. pleuropneumoniae* cytolysin type II genes by Southern blotting revealed that the B and D genes are not located immediately downstream from the *cytA* gene on the *Actinobacillus* chromosome. This is unusual, as the cytolysin C, A, B and D genes are clustered in the *A. pleuropneumoniae* cytolysin type I (Frey, J., and Nicolet, J., *J. Clin. Microbiol.* (1990) 28:232-236), *P. haemolytica* leukotoxin (Strathdee, C.A. and Lo, R.Y.C., *Infect. Immun.* (1989) 171:916-928), and the *E. coli* alpha hemolysin (Welch, R.A. and Pellet, S.A. *J. Bacteriol.* (1988) 170:1622-1630).

*E. coli* HB101 containing plasmid pCY76/503 expressed the recombinant cytolysin (CytA) as inclusion bodies upon induction with IPTG. The protein made up 30% of the total protein content in the pCY76/503 transformants. Isolated protein aggregates were estimated to be 75% pure. The resulting protein could be detected by *A. pleuropneumoniae* convalescent serum and by antibodies raised against the *A. pleuropneumoniae* type 1 cytolysin-containing culture supernatant. Restriction endonuclease maps of the cytolysin gene and sequence data are shown in Figures 5 and 4.

-49-

Example 5

Isolation and Characterization of Spontaneous  
Mutants of the cytA Gene

Spontaneous deletions of the *cytA* gene from the

5    *A. pleuropneumoniae* chromosome occur at high frequency (approximately 1/10,000 colonies), as determined by reaction with monospecific antisera against the cytolysin. In order to isolate and characterize the spontaneous mutants, *A. pleuropneumoniae* strains AP76 and

10   AP205 were subcultured twice from single colonies. Two independent serial dilutions were made for each strain, and from each approximately 10,000 colonies were plated. After replica-plating onto nitrocellulose, three independent cytolysin-negative colonies were detected by

15   immunoblot and designated AP76Δ1, AP205Δ1, and AP205Δ2. Western blot analysis of whole cell lysates revealed that these colonies lacked the cytolysin whereas the Coomassie blue stained total protein profile appeared to be identical with the wildtype. Southern blot analysis of

20   restricted DNA from AP76Δ1 and AP205Δ1 with  $\lambda$ CY76/5-derived probes revealed that the *Bgl*III fragment was absent, although hybridization was observed after using the *Bgl*III fragment as a probe. Hybridization with the *Bgl*III-EcoRI fragments located on either end of  $\lambda$ CY76/5

25   resulted in the appearance of strong bands in the cytolysin-negative mutants, and the hybridizing EcoRI fragment appeared to be approximately 7 kb smaller than that in the wildtype.

In order to characterize the *cytA* excision

30   site, a genomic library was prepared from AP76Δ1 and probed with the EcoRI fragment derived from  $\lambda$ CY76/5. Several clones were isolated, and initial characterization revealed that one clone had a *Bam*HI-*Kpn*I fragment identical in size to that of  $\lambda$ CY76/5. This

35   clone was designated as  $\lambda$ CY76Δ1/1. Also, the nucleotide

sequence of the *Bam*HI-*Kpn*I fragment of this clone was identical to the corresponding region of  $\lambda$ CY76/5. Part of this sequence was present a second time on  $\lambda$ CY76/5 starting 358 bp downstream from the end of *cytA* (Figures 5 14 and 15). Further analysis showed that *cytA* is flanked by two identical direct repeats each being 1201 bp in length, and that one repeat is completely conserved in  $\lambda$ CY76/Δ1. The sequence flanking the direct repeats located on either site of the *cytA* gene in  $\lambda$ CY76/5 is 10 TTAATG---AATATT, and this sequence does not comprise part 10 of an apparent longer reading frame (Figure 16). An initial analysis of the repeat sequence revealed that its ends form complementary repeats with 4 mismatches over a length of 26 bp. They also contain one open reading 15 frame going in the opposite direction than *cytA*. The open reading frame is 1038 nucleotides long and preceded by a Shine-Dalgarno consensus sequence.

#### Example 6

##### 20 The Protective Capacity of Serotype 7 Recombinant Proteins

*E. coli* HB101 strains expressing the transferrin binding protein and the 103 kDa cytolysin were grown to mid log phase in 50 ml broth cultures and 25 induced by the addition of 2 mM IPTG. After two hours of vigorous shaking at 37°C, cells were harvested by centrifugation and resuspended in 2 ml 50 mM of Tris-HCl, pH 8, 25% sucrose, and frozen at -70°C. The cell suspension was thawed, 5 µg of lysozyme added and after 5 30 min on ice, 10 ml of detergent mix was added to lyse cells. The lysed cell suspension was sonicated to reduce viscosity and protein aggregates were harvested by centrifugation for 30 min at 15,000 g. The aggregated protein was resuspended in double distilled water to a 35 concentration of 5-10 mg/ml and solubilized by the

-51-

addition of an equal volume of 7 M guanidine hydrochloride. The solubilized protein was diluted in distilled water to 1 mg/ml and emulsified in Amphigen (Smith-Kline Beecham, Lincoln, NE) with Tween80 (Sigma 5 Chemical Co., St. Louis, MO) and Span (Sigma Chemical Co., St. Louis, MO) using a Polytron homogenizer (Kinematica GmbH, Littau, Switzerland). Each 2 ml dose of vaccine contained Amphigen (100  $\mu$ l), Tween80 (28  $\mu$ l), Span (12  $\mu$ l), guanidine hydrochloride (20 mmol), and 10 protein as indicated below.

Trial 1: 48 pigs were randomly assigned to 8 groups and immunized by intramuscular injection in the neck muscle twice (on days 1 and 21) as follows: 15 2 groups received 25  $\mu$ g of recombinant CytA, 2 groups received 25  $\mu$ g of recombinant *A. pleuropneumoniae* serotype 7 60 kDa protein, 2 groups received both proteins, and 2 groups (unimmunized controls) received the adjuvant only. One set of 4 groups was subsequently challenged on day 32 with *A. pleuropneumoniae* serotype 1 20 strain AP37 ( $4.1 \times 10^5$  CFU/ml), the other one with *A. pleuropneumoniae* serotype 7 strain AP205 ( $1.4 \times 10^8$  CFU/ml).

Trial 2: 24 pigs were randomly assigned to 4 groups, and the groups twice received 0, 12.5, 50, or 25 200  $\mu$ g recombinant *A. pleuropneumoniae* serotype 7 60 kDa protein. Subsequently, all groups were challenged with  $7 \times 10^8$  CFU/ml of *A. pleuropneumoniae* serotype 7 strain AP205.

30 Clinical data plus body temperatures were recorded daily for 3 days post challenge and each animal received a daily average clinical score. The scoring system is defined as follows: 0 - clinically normal; 1 - slight increase in respiratory rate and effort, slight depression; 2 - marked increase in respiratory rate and effort, marked depression; 3 - severe increase 35

in respiratory rate and effort, severe depression, mouth breathing and/or cyanotic. Animals with a clinical score of 3 were euthanized.

In addition, serum samples collected at days 0, 5 21 and 28 of the trial were used to determine the serological response to vaccination by an enzyme linked immunosorbent assay (ELISA). All serum samples were titrated in the ELISA against the recombinant serotype 7 60 kDa transferrin binding protein, the recombinant 10 cytolysin protein, as well as against an A. *pleuropneumoniae* serotype 7 and serotype 1 extract (Willson, P.J., et al., *Can. Vet. J.* (1988) 29:583-585). Briefly, plates were coated overnight at 4°C with 100 µl 15 of a solution containing either 1 µg/ml of recombinant protein or 10 µg/ml of extract protein in carbonate buffer. Plates were blocked for 1 h at room temperature with 0.5% gelatine in washing buffer (150 mmol saline, 30 mmol Tris-HCl, 0.05% Tween20). An internal standard consisted of a pool of equal volumes of swine antisera to 20 A. *pleuropneumoniae* serotype 1 and serotype 7 that was diluted 1:100 in washing buffer. Serum dilutions and goat-anti-pig alkaline phosphatase conjugate (Kirkegaard & Perry Laboratories, Inc., Gaithersburg, MD) were each 25 left to incubate for 1 h at room temperature. Plates were developed at 37°C with 100 µl p-nitrophenyl phosphate (3 g/l) in 1 mol diethanolamine, 50 mmol MgCl<sub>2</sub>, pH 9.8. The development time was varied for the different coating antigens such that the control serum had a titer between 1:800 and 1:1600 (10 min for the 30 cytolysin, 20 min for the A. *pleuropneumoniae* serotype 1 extract, 45 min for the 60 kDa protein, 90 min for the A. *pleuropneumoniae* 7 extract).

The trials were terminated on day 40, and all surviving pigs were euthanized. The injection sites were 35 examined, and lungs were scored to determine the

-53-

percentage of pulmonary area affected by lesions using a computerized digitizer. Lungs were cultured to determine the presence of *A. pleuropneumoniae* and to confirm its serotype.

5 The significance of the difference in mortality rates among the different groups was determined using a G<sup>2</sup> likelihood ratio test (Dixon, W.J., et al., BMDP Statistical Software Manual, University of California Press, 1988, pp. 229-273.

10 The results are summarized in Tables 2 and 3. As can be seen, all pigs in Trial 1 developed a strong antibody response to the recombinant antigen with which they had been immunized (Table 2). There was a significant difference ( $p < 0.03$ ) in mortality among the 15 8 groups. After challenge with *A. pleuropneumoniae* serotype 7 (strain AP205), the mortality in all immunized groups was lower than in the control group ( $p < 0.1$ ). Also, the damage to the lungs of immunized pigs may be less extensive than that seen in the control pigs (Table 20 2). This outcome was reflected by a generally milder course of disease shown by lower body temperature and clinical scores during the first 3 days after challenge (Figures 12A and 12B). Pigs that developed an antibody response against both recombinant antigens showed a 25 particularly mild course of disease (Figures 12A and 12B), and damage to their lungs was minimal (Table 2).

30 All pigs in trial 2 developed a strong antibody response to the 60 kDa protein, and the titers were independent of the dose (Table 3). The immunized groups had a lower mortality than the control group ( $p = 0.14$ ), and the lesion score of the lungs from pigs in group H was also reduced for immunized pigs (Table 2). These results are supported by the clinical data obtained in the first 3 days after challenge (Figures 13A and 13B).

Both mortality and clinical data do not show an increased efficacy of the higher antigen dose.

In both trials, the injection sites were free of macroscopically detectable alterations. In all pigs, *A. pleuropneumoniae* was isolated from the lungs 1 week after challenge.

In agreement with previous findings, our results show a lack of protection against a heterologous serotype despite an appreciable serum titer in the animals (Table 2). This lack of cross-protection could be explained by two observations:

(1) The *A. pleuropneumoniae* serotype 1 challenge strain not only expressed the 103 kDa cytolysin but, in addition, expressed a serologically distinct 105 kDa cytolysin. This is in accordance with the results of Kamp, E.M., et al., Abstr. CRWAD (1990) 1990:270, who described the presence of these two cytolysins in an *A. pleuropneumoniae* serotype 1 strain. Therefore, the lack of protection against heterologous challenge could not only be caused by serotype-specific differences of the 103 kDa cytolysin, but it could also indicate that the activity of one cytolysin is sufficient to allow subsequent colonization by the pathogen.

(2) The *A. pleuropneumoniae* serotype 1 and 7 challenge strains express different 60 kDa proteins. Thus, Southern hybridization of chromosomal DNA from the *A. pleuropneumoniae* serotype 1 challenge strain with the *tfbA* probe did not result in binding under high stringency conditions, and serum raised against the 60 kDa protein did not react strongly with *A. pleuropneumoniae* serotype 1 grown under iron-restricted conditions. The observations concerning the genetic and antigenic differences of the 60 kDa proteins in *A. pleuropneumoniae* serotype 1 and 7 strains, as well as the presence of two different cytolysins in

-55-

A. *pleuropneumoniae* serotype 1 strains, explain these results. Therefore, these findings suggest that a vaccine containing at least two serologically and functionally distinct *A. pleuropneumoniae* cytolysins, as 5 well as serotype-specific 60 kDa proteins, might offer cross-protection against clinical symptoms.

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Table 2  
Mortality, Lung Damage, and Serological Response of Pigs Vaccinated With Recombinant Cytolysin and 60K-protein (Trial 11)

Group	Antigen for Vaccination	Mortality <sup>1</sup>	% Lung Damage <sup>2</sup>	Cytolysin	Serotiter <sup>3</sup>	Body Temperature <sup>4</sup>	Clinical Score
<b>A. <i>pleuropneumoniae</i> Challenge Strain: AP 205 (serotype 7)</b>							
1	None	4/6	17.5 ± 10.4	<200	<200	40.7 ± 0.2	1.75
2	Cytolysin	0/6	14.1 ± 15.5	2400	<200	40.1 ± 0.5	0.625
3	60 kDa Protein	1/6	26.5 ± 26.4	<200	9600	40.4 ± 0.7	1.0
4	Cytolysin and 60 kDa Protein	1/6 <sup>5</sup>	3.7 ± 4.5	800	19.200	39.7 ± 0.3	0.25
<b>A. <i>pleuropneumoniae</i> Challenge Strain: AP 37 (serotype 1)</b>							
5	None	4/6	--	<200	<200	41.4 ± 0.3	2.0
6	Cytolysin	5/6	--	1600	<200	41.8 ± 0.6	1.875
7	60 kDa Protein	4/6	--	<200	19.200	41.4 ± 0.2	1.5
8	Cytolysin and 60 kDa Protein	4/6	--	1600	6400	41.2 ± 0.6	1.75

(see next page for notes)

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Table 2 (cont.)  
Mortality, Lung Damage, and Serological Response of Pigs Vaccinated With  
Recombinant Cytolysin and 60K-protein (Trial 1)

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- 1 Number of pigs that died or were euthanized in extremis over the total in the group.
- 2 The lung damage was assessed only for pigs surviving until day 7 after challenge.
- 3 The serotiter is the median of the individual titers determined at the date of challenge.
- 4 Arithmetic mean body temperature (c) for survivors on the second day after challenge.
- 5 The dead pig did not develop a serotiter against the cytolsin.

-58-

Table 3

Mortality, Lung Damage, and Serological Response of Pigs Vaccinated With Different Amounts of Recombinant 60 kDa Protein (Trial 2)

Challenge Strain	Group	Vaccination	Mortality <sup>1</sup>	% Lung Damage <sup>1</sup>	Amount [µg] of	
					Antigen for	Serotiter <sup>2</sup>
A. pleuropneumoniae	1	None	3/6	8.6 ± 6.1	51.200	<200
	2	200	1/6	7.0 ± 4.9		
	3	50	1/6	11.9 ± 15.0		
	4	12.5	0/6	7.3 ± 10.2		

<sup>1</sup> The lung damage was assessed only for pigs surviving until day 7 after challenge.  
<sup>2</sup> The serotiter is the median of the individual titers determined at the date of challenge.

-59-

Example 7

Cloning of *A. Pleuropneumoniae*  
Serotype 5 Protective Proteins

A genomic library of *A. pleuropneumoniae*

5 serotype 5 strain AP213 was prepared by partially digesting chromosomal DNA with *Sau3AI* and ligating into the *BamHI* site of the phage vector  $\lambda$ 2001 as described in Example 4. The library was screened under low stringency conditions with an *NsiI*-*KpnI* fragment from plasmid

10 pTF205/E1, which encodes the serotype 7 transferrin binding protein (*tfbA*), and with probes from the gene encoding the APP4 protein from serotype 1. The DNA from positive plaques of each type was purified and subcloned into expression vectors as follows. For the rAPP4 gene,

15 recombinant  $\lambda$ 2001 DNA was partially digested with *Sau3AI* and ligated into a *BamHI*-digested pGH432. The ligation mix was transformed into *E. coli* HB101. For the *tfbA* gene, an *NsiI* fragment from the recombinant phage was subcloned into the *NsiI* site of plasmid pTF205/E1, in

20 front of the serotype 7 *tfbA* gene. This ligation mix was also transformed into *E. coli* HB101. This construct was trimmed by digesting the plasmid completely with *BamHI* and partially with *Sau3AI* and religating. This eliminated the *A. pleuropneumoniae* serotype 7 *tfbA* gene

25 and non-coding DNA at the 3' end of serotype 5 *tfbA* the gene.

The recombinant plasmids expressing the serotype 5 *tfb* gene (pTF213/E6) and the rAPP4 gene (p#4-213-84) were shown to produce polypeptides of

30 approximately 62 kDa and 60 kDa, respectively, which reacted with convalescent serum from an *A. pleuropneumoniae* serotype 5-infected pig. In addition, serum raised against the recombinant *tfbA* protein reacted specifically with a 62 kDa protein of *A. pleuropneumoniae*

35 serotype 5.

-60-

Example 8

The Protective Capacity of Serotype 5

Recombinant Proteins

Serotype 5 recombinant transferrin binding

5 protein and recombinant APP4 were prepared as described in Example 7. Vaccines containing these recombinant proteins were prepared by solubilizing the proteins with guanidine hydrochloride and combining the resultant solution with the adjuvant Emulsigen Plus such that each 10 2 ml dose contained 25  $\mu$ g protein and 30% adjuvant, as described in Example 6.

Groups of four pigs were vaccinated as described in Example 6 with the recombinant vaccines and three pigs were immunized with a placebo containing 15 adjuvant only. All animals were boosted three weeks later, and after seven days all pigs were challenged with *A. pleuropneumoniae* serotype 5 strain AP213 ( $8 \times 10^5$  CFU/ml) by aerosol as described in Example 6. Clinical signs of disease were monitored daily for three days post 20 challenge, and one week after challenge. All surviving pigs were euthanized and their lungs were examined for pneumonic lesions.

As shown in Table 4, vaccination with either antigen eliminated mortality associated with *A. pleuropneumoniae* infection and reduced clinical signs of 25 disease.

-61-

Table 4

Mortality and Clinical Signs of Disease in Pigs  
Vaccinated with Recombinant Serotype 5  
Transferrin Binding Protein or APP4

5	Grp	Antigen for Vaccination	Mortality <sup>1</sup>	Clinical Score			% Lung Damage <sup>2</sup>
				Day 1	Day 2	Day 3	
10	1	Placebo	3/3	1.33	1.58	2.13	ND
	2	Tfb <sup>3</sup>	0/4	0.87	0.75	0.38	8.13
	3	rAPP4	0/4	1.31	1.25	1.37	18.73

<sup>1</sup> Number of pigs that died or were euthanized in extremis over the total in the group.

<sup>2</sup> The lung score was assessed only for pigs surviving until day 7 after challenge.

<sup>3</sup> Transferrin binding protein

20

Example 9

The Protective Capacity of Serotype 1

APP4 Protein

Serotype 1 recombinant APP4 was prepared as described in Example 7. Vaccines containing the APP4 protein were prepared by solubilizing the protein with guanidine hydrochloride and combining the resultant solution with the adjuvant Amphigen such that each 2 ml dose contained 25 µg protein and 30% adjuvant, as described in Example 6.

Groups of four pigs were vaccinated as described in Example 6 with the recombinant vaccine and three pigs were immunized with a placebo containing adjuvant only. All animals were boosted three weeks later, and after seven days all pigs were challenged with

-62-

5 *A. pleuropneumoniae* serotype 1 strain AP37 by aerosol as described in Example 6. Clinical signs of disease were monitored daily for three days post challenge, and one week after challenge. All surviving pigs were euthanized and their lungs were examined for pneumonic lesions.

As shown in Table 5, vaccination with APP4 reduced mortality associated with *A. pleuropneumoniae* infection and reduced clinical signs of disease.

10

**Table 5**

**Mortality and Clinical Signs of Disease in Pigs  
Vaccinated with Recombinant Serotype 1 APP4**

15	Group	Mortality <sup>1</sup>	Clinical Score		
			Day 1	Day 2	Day 3
	1 Placebo	3/5	2.20	1.00	0.75
	2 APP4	1/6	0.58	1.00	0.30

20 <sup>1</sup> Number of pigs that died or were euthanized in extremis over the total in the group.

25

Thus, subunit vaccines for use against *A. pleuropneumoniae* are disclosed, as are methods of making and using the same. Although preferred embodiments of the subject invention have been described in some detail, it is understood that obvious variations can be made without departing from the spirit and the scope of the invention as defined by the appended claims.

35

CLAIMS

1. A vaccine composition comprising a pharmaceutically acceptable vehicle and a subunit antigen composition, said subunit antigen composition comprising at least one amino acid sequence substantially homologous and functionally equivalent to an immunogenic polypeptide of an *Actinobacillus pleuropneumoniae* protein, said *Actinobacillus pleuropneumoniae* protein selected from the group consisting of an *Actinobacillus pleuropneumoniae* transferrin binding protein, an *Actinobacillus pleuropneumoniae* cytolysin and an *Actinobacillus pleuropneumoniae* APP4.
- 15 2. The vaccine composition of claim 1 wherein said immunogenic polypeptide is an *Actinobacillus pleuropneumoniae* transferrin binding protein, or an immunogenic fragment thereof.
- 20 3. The vaccine composition of claim 2 wherein said immunogenic polypeptide is an *Actinobacillus pleuropneumoniae* serotype 7 transferrin binding protein having a molecular mass of approximately 60 kDa, as determined by SDS PAGE.
- 25 4. The vaccine composition of claim 3 wherein said transferrin binding protein has an amino acid sequence substantially as depicted in Figure 1.
- 30 5. The vaccine composition of claim 2 wherein said immunogenic polypeptide is an *Actinobacillus pleuropneumoniae* serotype 5 transferrin binding protein having a molecular mass of approximately 62 kDa, as determined by SDS PAGE.

6. The vaccine composition of claim 2 wherein  
said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* serotype 1 transferrin binding protein  
having a molecular mass of approximately 65 kDa, as  
5 determined by SDS PAGE.

7. The vaccine composition of claim 6 wherein  
said transferrin binding protein has an amino acid  
sequence substantially as depicted in Figure 2.

10

8. The vaccine composition of claim 1 wherein  
said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* cytolysin, or an immunogenic fragment  
thereof.

15

9. The vaccine composition of claim 8  
wherein said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* serotype 7 cytolysin having a molecular  
mass of approximately 103 kDa, as determined by SDS PAGE.

20

10. The vaccine composition of claim 1 wherein  
said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* APP4.

25

11. The vaccine composition of claim 10  
wherein said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* serotype 1 APP4.

30

12. The vaccine composition of claim 10  
wherein said immunogenic polypeptide is an *Actinobacillus*  
*pleuropneumoniae* serotype 5 APP4.

35

13. The vaccine composition of claim 1 wherein  
said subunit antigen composition comprises an  
Actinobacillus *pleuropneumoniae* transferrin binding

-65-

protein, or an immunogenic fragment thereof, and an *Actinobacillus pleuropneumoniae* cytolysin, or an immunogenic fragment thereof.

5 14. The vaccine composition of claim 13 further comprising an *Actinobacillus pleuropneumoniae* APP4.

10 15. The vaccine composition of claim 1 further comprising an adjuvant.

15 16. A nucleotide sequence encoding an *Actinobacillus pleuropneumoniae* transferrin binding protein or a protein substantially homologous and functionally equivalent thereto.

20 17. The nucleotide sequence of claim 16 wherein said transferrin binding protein comprises an amino acid sequence substantially as depicted in Figure 1.

25 18. The nucleotide sequence of claim 16 wherein said transferrin binding protein comprises an amino acid sequence substantially as depicted in Figure 2.

30 19. The nucleotide sequence of claim 16 wherein said transferrin binding protein comprises an amino acid sequence substantially as encoded by the nucleotide sequence present in recombinant plasmid pTF213/E6.

20. A nucleotide sequence encoding an *Actinobacillus pleuropneumoniae* APP4 protein or a protein

substantially homologous and functionally equivalent thereto.

5

21. The nucleotide sequence of claim 20 wherein said APP4 protein comprises an amino acid sequence substantially as encoded by the nucleotide sequence present in recombinant plasmid prAPP4.

10

22. The nucleotide sequence of claim 20 wherein said APP4 protein comprises an amino acid sequence substantially as encoded by the nucleotide sequence present in recombinant plasmid p#4-213-84.

15

23. A DNA construct comprising an expression cassette comprised of:

(a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* transferrin binding protein; and

20 (b) control sequences that are operably linked to said coding sequence whereby said coding sequence can be transcribed and translated in a host cell, and at least one of said control sequences is heterologous to 25 said coding sequence.

24. The DNA construct of claim 23 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 7 60 kDa transferrin 30 binding protein.

25. The DNA construct of claim 23 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 5 62 kDa transferrin 35 binding protein.

26. The DNA construct of claim 23 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 1 65 kDa transferrin binding protein.

5

27. A DNA construct comprising an expression cassette comprised of:

(a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* cytolysin; and

10 (b) control sequences that are operably linked to said coding sequence whereby said coding sequence can be transcribed and translated in a host cell, and at least one of said control sequences is heterologous to 15 said coding sequence.

20 28. The DNA construct of claim 27 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 7 103 kDa cytolysin.

25 29. A DNA construct comprising an expression cassette comprised of:

(a) a DNA coding sequence for a polypeptide containing at least one epitope of an *Actinobacillus pleuropneumoniae* APP4; and

30 (b) control sequences that are operably linked to said coding sequence whereby said coding sequence can be transcribed and translated in a host cell, and at least one of said control sequences is heterologous to said coding sequence.

35 30. The DNA construct of claim 29 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 1 APP4.

31. The DNA construct of claim 29 wherein said DNA coding sequence encodes at least one epitope of an *Actinobacillus pleuropneumoniae* serotype 5 APP4.

5

32. A host cell stably transformed by a DNA construct according to any of claims 23-31.

33. A method of producing a recombinant 10 polypeptide comprising:

(a) providing a population of host cells according to claim 32; and

(b) growing said population of cells under conditions whereby the polypeptide encoded by said 15 expression cassette is expressed.

34. A method of treating or preventing pneumonia in swine comprising administering to said swine a therapeutically effective amount of a vaccine 20 composition according to any of claims 1-15.

35. Isolated and purified *Actinobacillus pleuropneumoniae* serotype 7 60 kDa transferrin binding protein.

25

36. Isolated and purified *Actinobacillus pleuropneumoniae* serotype 5 62 kDa transferrin binding protein.

30

37. Isolated and purified *Actinobacillus pleuropneumoniae* serotype 1 65 kDa transferrin binding protein.

35

38. Isolated and purified *Actinobacillus pleuropneumoniae* serotype 1 APP4.

-69-

39. Isolated and purified *Actinobacillus*  
*pleuropneumoniae* serotype 5 APP4.

5

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FIGURE 1

## FIGURE 1 CONT'D

## FIGURE 1 CON'T'D

## FIGURE 1 CONT'D

## FIGURE 1 CONT'D

FIGURE 1 CONT'D

7 / 26

FIGURE 1 CONT'D

## FIGURE 2

9 / 26

## FIGURE 2 CON'T'D

10/26

FIGURE 2 CON'T'D

11/26

1090	1100	1110	1120	1130	1140	1150	1160	1170
•	•	•	•	•	•	•	•	•
GAT GCA ACT AAA ATT GAT TTA ACC CAA TTT AAT GCT AAA GAA CTC AAC AAT TTT EGT GAT GCC TCT GGT TTA ATT GAT GGA CAA AAA								
CTA CGT TGA TTT TAA CTA AAT TGG GGT AAA TTA CGA TTT CTT GAG TTG TTA AAA CCA CCA CGG AGA CAA CAA ATT TAA TAA CTA CCT GGT TTT								
Asp Ala Thr Lys Ile Asp Leu Thr Glu Phe Asn Ala Lys Glu Leu Asn Asn Phe Glu Asp Ala Ser Val Leu Ile Asp Glu Glu Lys)								
•	•	•	•	•	•	•	•	•
1180	1190	1200	1210	1220	1230	1240	1250	1260
•	•	•	•	•	•	•	•	•
ATA GAT CTA GCA GGT GTC AAT TTT AAA AAT AGT AAA ACG GGT GAA ATC AAC GGC AAA ACA ATG GTC GGC GTC GCT GTC TGT AGT AAT CTG								
TAT CTA GAT CGT CCA CAA TAA TTT TAA TCA TTT TGC CAA CTT TGC TAA CTT TAG TTT TGT TAC CAT CGG CAT CGA AGG AGA TCA TTA GAC								
Ile Asp Leu Ala Glu Val Asn Ser Lys Thr Val Glu Ile Asn Glu Lys Thr Met Val Ala Val Ala Cys Cys Ser Asn Leu)								
•	•	•	•	•	•	•	•	•
1270	1280	1290	1300	1310	1320	1330	1340	1350
•	•	•	•	•	•	•	•	•
GAA TAT ATG AAA TTT GGT CAA TTG TGG CAA AAA GAG GGC AAA CAA CAA GGT AAA GAT MAT AGT TTA TTC CTA CAA GGT GAA CGT ACT GCA								
CTT ATA TAC TTT AAA CCA GGT ATC ACC GGT TTT CTC CGG TTT GGT GGT CAA ATT CAA ATT CAA ATT AGG GAT GGT CCA ATT GCA TGA CGT								
Glu Tyr Met Lys Phe Glu Glu Leu Trp Glu Lys Glu Glu Lys Glu Glu Val Lys Asp Asn Ser Leu Phe Leu Glu Glu Arg Thr Ala)								
•	•	•	•	•	•	•	•	•

FIGURE 2 CONT'D

12 / 26

## FIGURE 2 CONT'D

## FIGURE 2 CONT'D

TF37 - MHFKLNPyALAFTSLFLVACSGGKGSDLEDVRPNQTAKEKATTSYQDE -50  
 TF205 - MHFKLNPyALAFTSLFLVACSGGKGSDLEDVRPNKTTGVSKEE--YKDV -48  
 TF37 - ETKKKTKEELDKLMEPALGYETQILRRNKAPEKETGEKRNERVVELSEDK -100  
 TF205 - ETAKKEKEQLGELMEPALGYVVKVP----- -73  
 TF37 - ITKLYQESVEIIPHLDELNGKITSNDVYHSHDSKRLD----- -137  
 TF205 - -----VSSFENKKVDISDIEVITNGNLD -96  
 TF37 - -----KNDLKYVRSGYVYDG---SFNEIRRNDSGFH -166  
 TF205 - DVPLYKANSSSKYNYPDIKTDSSLQYVRSGYVIDGEHSGSNE----- -137  
 TF37 - VFKQGIDGYVYYLGVTPSKELPKGKVISYKGTMDFVSNINLEREIDGFTD -216  
 TF205 - ::::::: : : ::::: : : ::::: : : ::::: : : :::  
 TF37 - -----KGYVYYKGNSPAKELPVNQLLTYTGSMDFTSNANL----- -172  
 TF37 - SGDGNVSAKSITETVNRDHVKGEKLGNEVKGVAH----- -252  
 TF205 - -----NNEEGRPNYLNDDYYTKFIGKR -194  
 TF37 - -----SSEFAVDFDNKKLTGSLYRNGYINRNKAQEVTKRY -287  
 TF205 - VGLVSGDAIKPAKKYTSQFEVDFATKQMTGKL-----SDKEKTIY -234  
 TF37 - SIEADIAGNRFRGKAKA-----EKAGDPIFTDSNYLEGGFYGPKAEM -330  
 TF205 - TVNADIRGNRFTGAATASDKNKGKGESYNFFSADSQSLEGGFYGPKAEM -284  
 TF37 - AGKFFTNNKSLFAVFAAKSENGETTERIIDATKIDLTQFNAKELNNGFD -380  
 TF205 - AGKFVANDKSLFAVFSAKHNGSNVNTVRIIDASKIDLTNFSISELNNGFD -334  
 TF37 - ASVLIIDGOKIDLAGVNFKNSKTVEINGKTMVAVACCSNLEYMKFGQLWQ -430  
 TF205 - ASVLIIDGKKIKLAGSGFTNKHTIEINGKTMVAVACCSNLEYMKFGQLWQ -384  
 TF37 - KEGKQQVKDNSLFLQGERTATDKMPAGGNYKYVGTWDALVSKGTNWIAEA -480  
 TF205 - QAEGGKPENNSLFLQGERTATDKMPKGGNKYIGTWDQVSKENNWATA -434  
 TF37 - DNNRESGYRTEFDVNFSDKVNGKLFDKGGVNPVFTVDATINGNGFIGSA -530  
 TF205 - DDDRKAGYRTEFDVDFGNQNLSGKLFDKNGVNPVFTVDAKIDGNGFTGKA -484  
 TF37 - KTSDESGFALDAGSSQHGNAVFSDIKVNGGFYGPATAGELGGQFHHKSDNGS -580  
 TF205 - KTSDEGFALDSGSSRYENVKFNDVAVSGGFYGPAAELGGQFHHKSENGS -534  
 TF37 - VGAvgakrQIEK -593  
 TF205 - VGAvgakQqvKK -547

FIGURE 3

CTGTTATAGA TCTAGGAAAA GCAAGTTAG GTTGACAT TATCTCTGGT  
BgIII  
TTACTTCTG GAGCATCTGC AGGTCTCATT TTAGCAGATA AAGAGGCTTC  
AACAGAAAAAG AAAGCTGCCG CAGGTGTTAGA ATTGCTAAC CAAATTATAG  
GTAATGTAAC AAAAGCGGTC TCATCTTACA TTCTTGCCCA ACGAGTCGCT  
TCAGGTTTGT CTTCAACTGG TCCTGTCGCT GCATTAATCG CATCTACAGT  
TGCACTAGCT GTTAG

FIGURE 4

16/26

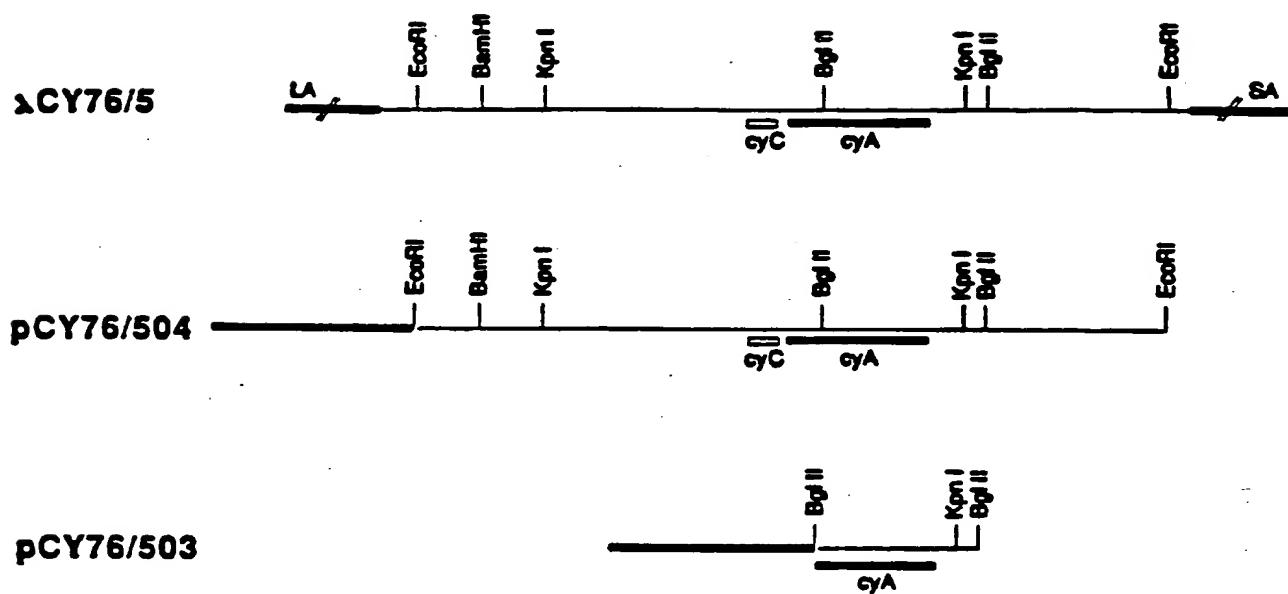
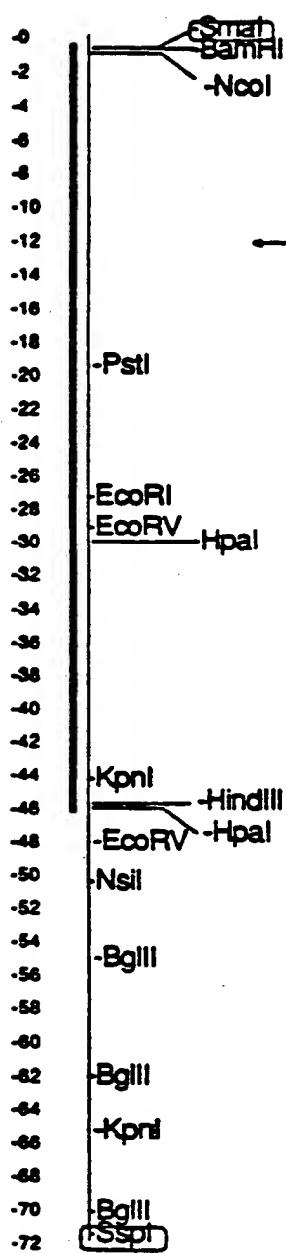
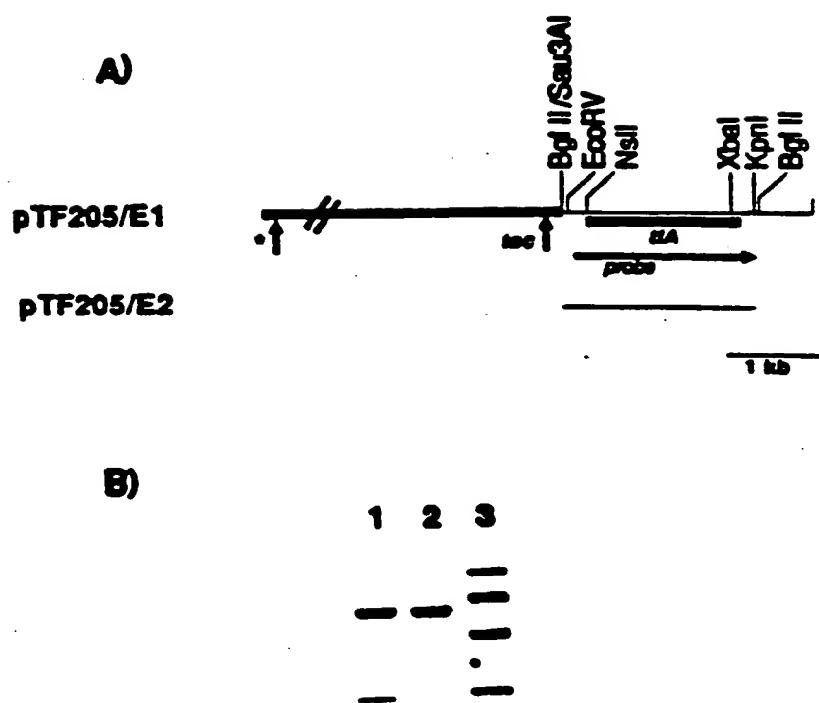


FIGURE 5

17/26



18/26



19/26

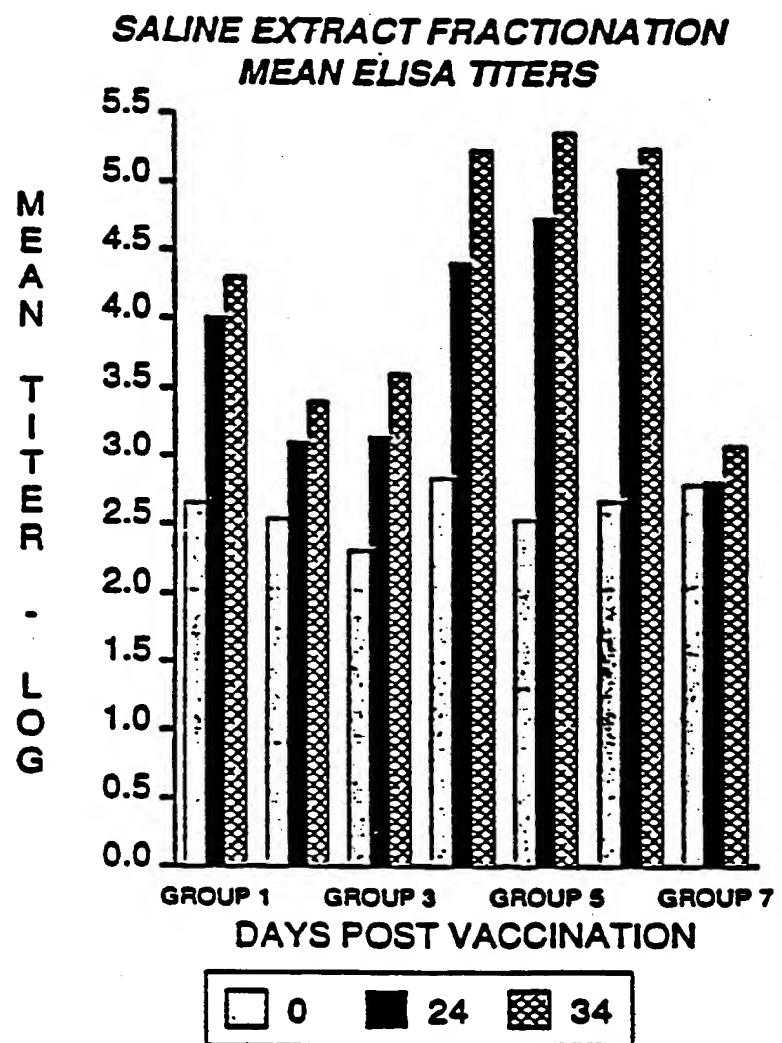
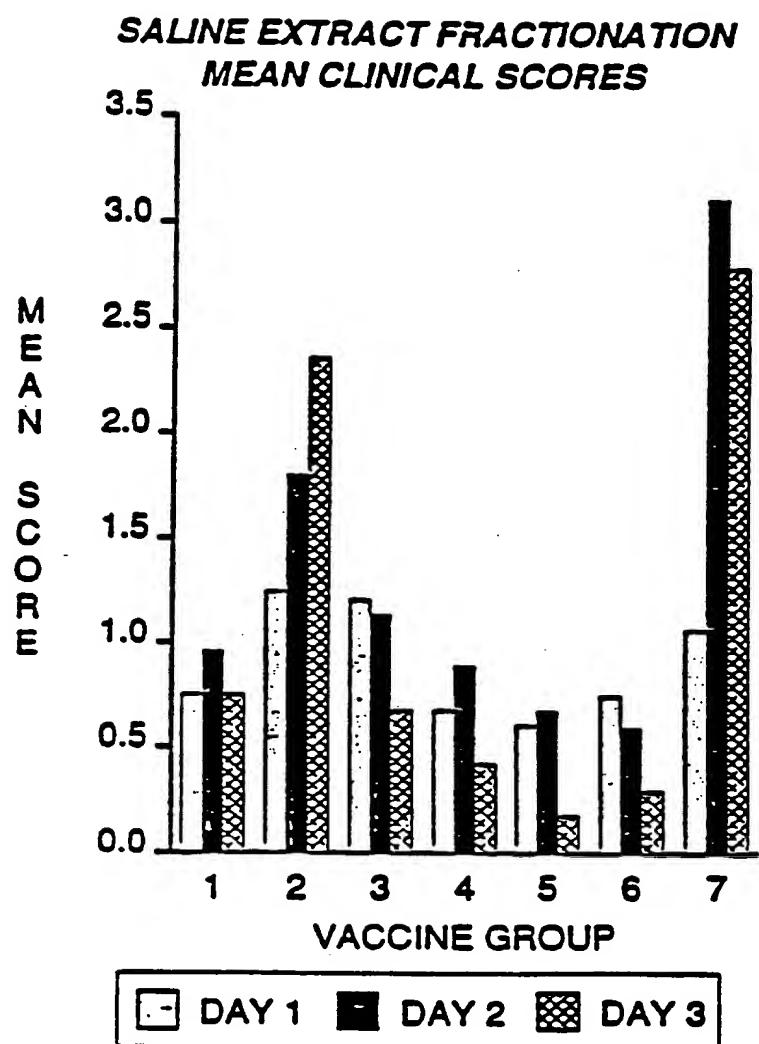


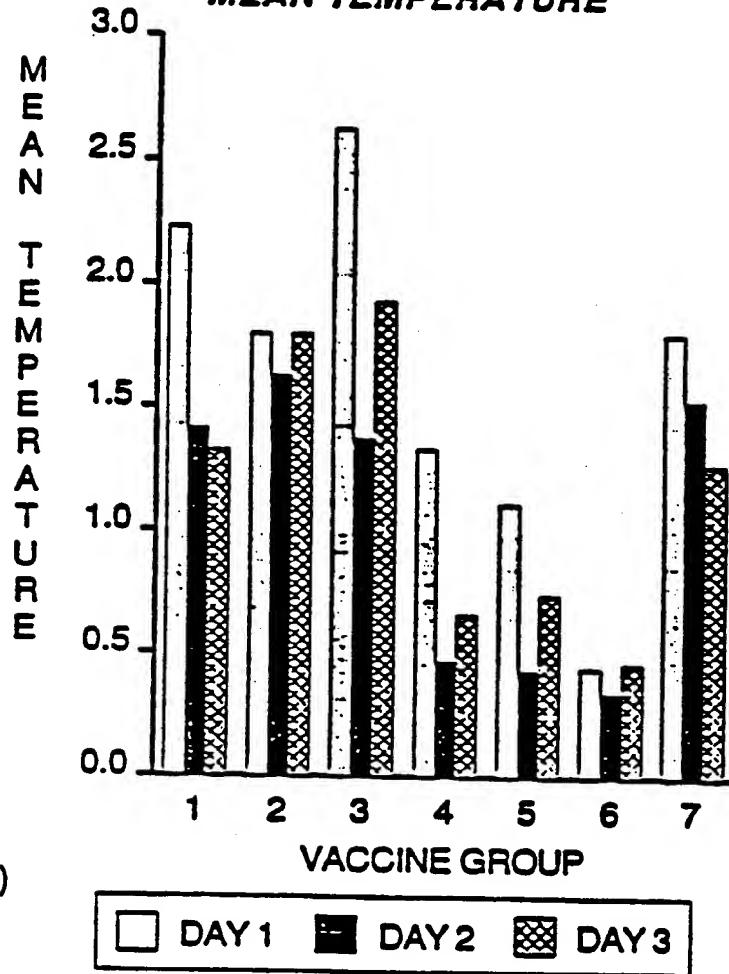
FIGURE 8

20/26

**FIGURE 9**

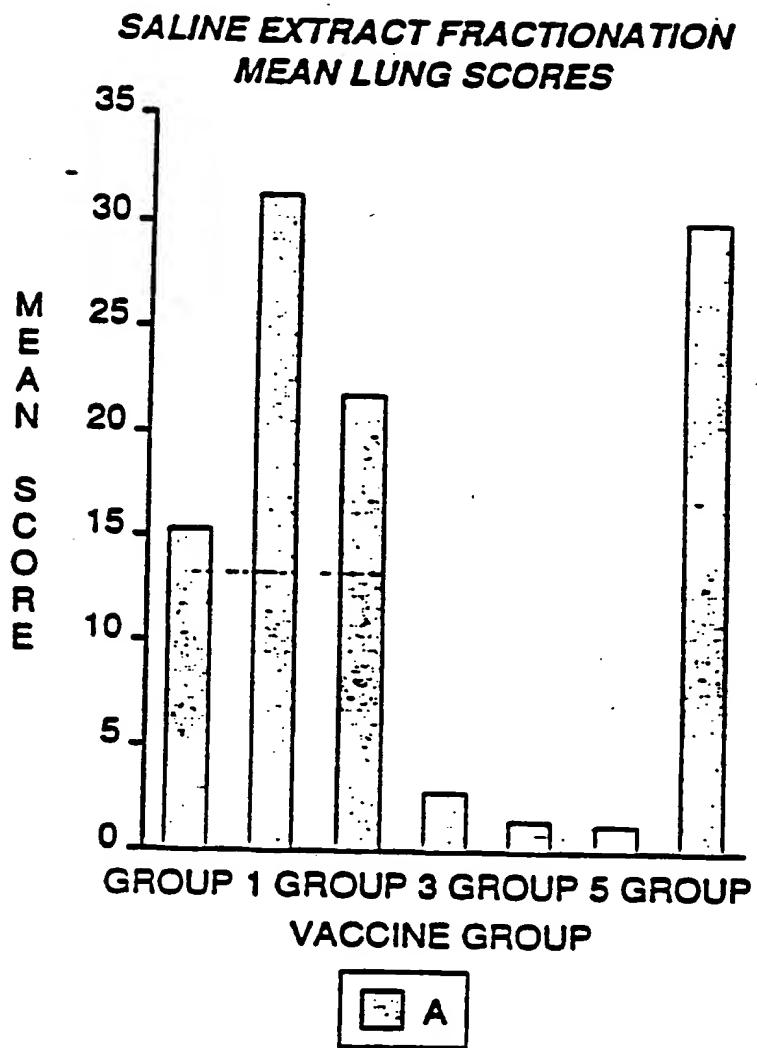
21/26

**PROTECTIVE EXTRACT FRACTIONATION  
MEAN TEMPERATURE**



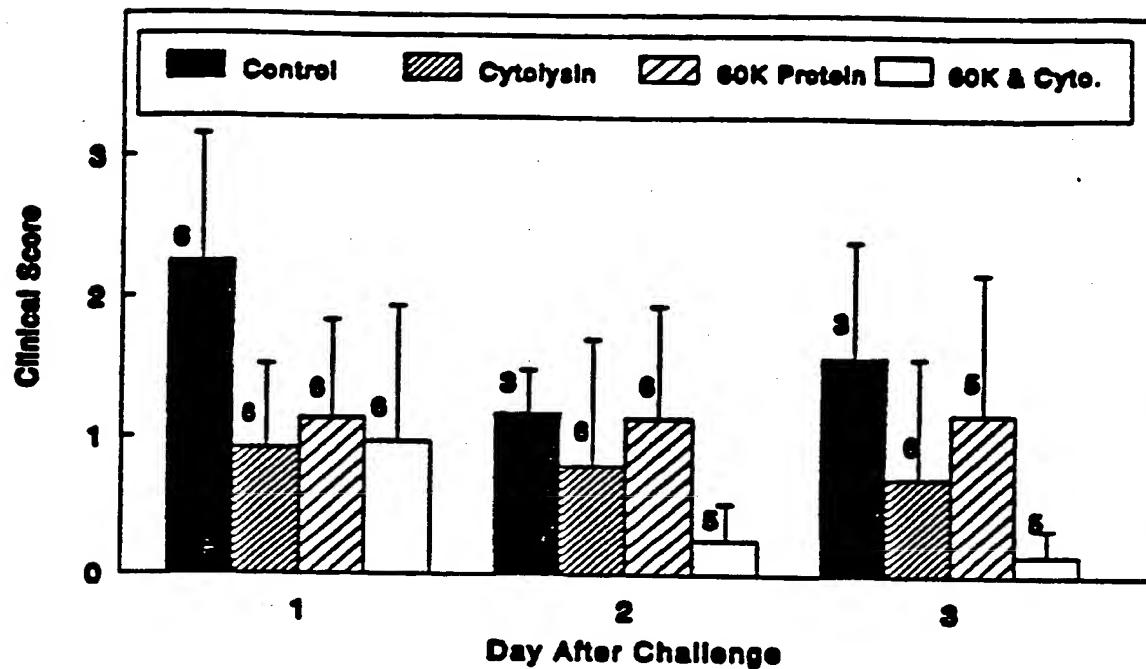
**FIGURE 10**

22/26

**FIGURE 11**

23/26

## Clinical Response After Challenge

**A**

## Body Temperature After Challenge

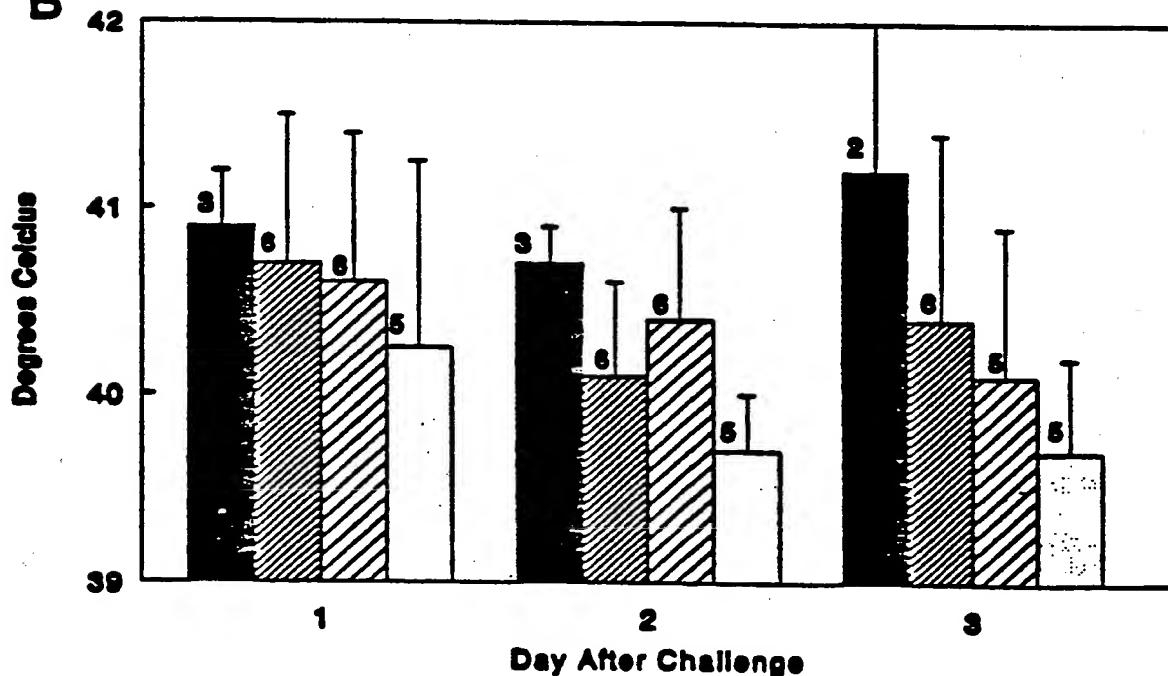
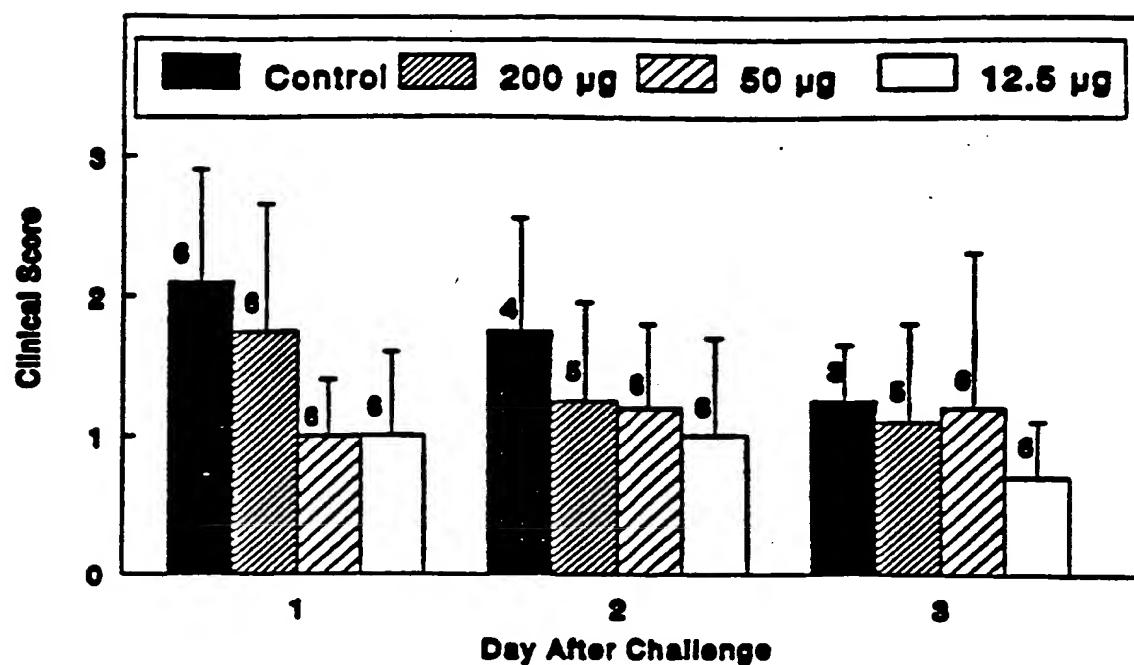
**B**

FIGURE 12

24/26

## Clinical Response After Challenge

**A**

## Body Temperature After Challenge

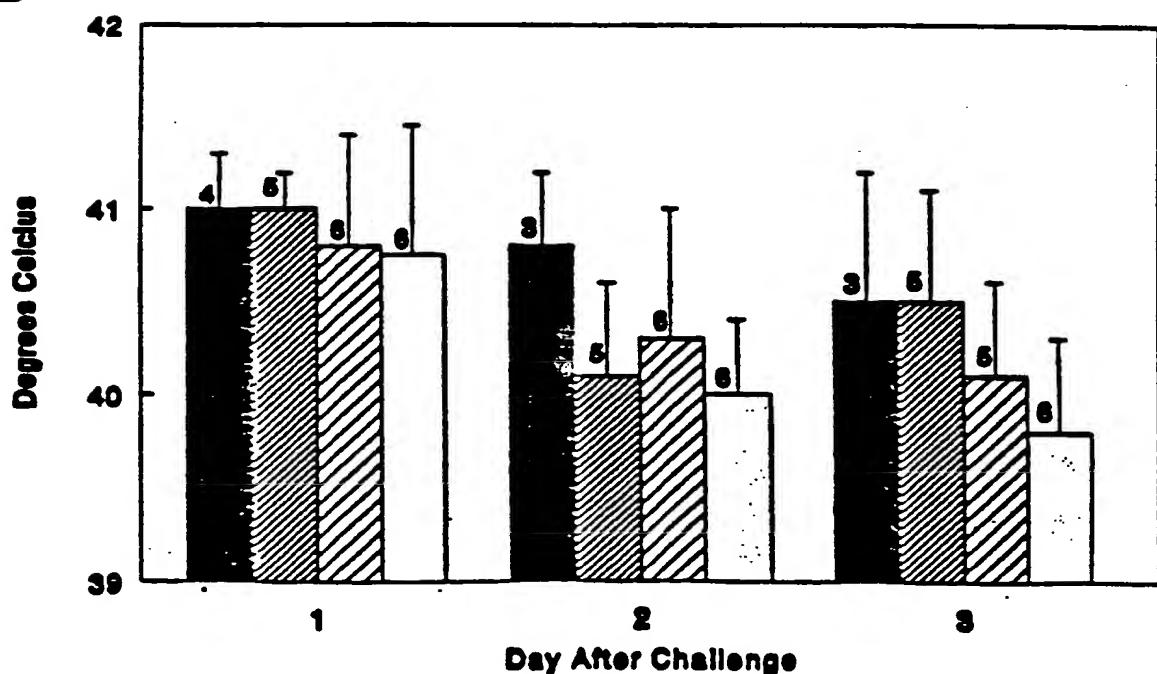
**B**

FIGURE 13

25/26

a

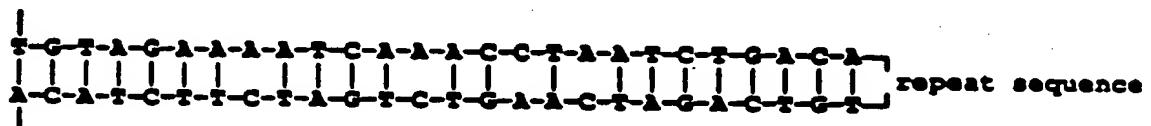
Samey -----/----|<----- CTTAATGATA TAACAGCGGT CAAATTCTAA  
 1201 bp repeat

AATCTTTGC AATGTGCAAC TTTTATTAGG ATT -----/----- **CytA** -/-  
 TCTAGATGGA AAAGGTTTGT CTTTAACATC ATGGTTAACATC GCAGCAAAAT CATTAGATT  
~~XbaI~~  
 AAAAGCAAAAG GCTATTAAATA AAAGCCGTTGA GCGTTTACCT TTTGTTAATT TACCTGCAC  
 TATCTGGAGG AAAGATGGAA AACATTTAT CTTAGTAAAG ATAGATAAAAG ATAAAAAAACG  
 CTATTTAAC |<-----| ---//---BglII  
 1201 bp repeat

FIGURE 14

b

diverging sequence



diverging sequence

FIGURE 15

26/26

1 CGATCCTGTT CTTGGTGAAA GTGTGGAAC TAAAGTTAAC TTATGTTAG AGAAAAAAGG  
 61 ATGGTATCTA GAGCAAGGTC CAGTGTGTGA AGAAAAAATAC GTATGGAATG AACCGGAATG  
 121 TATTAATGG CGAGCAAAAT ATAGTAAGCC AAAATGTGAA CCTTGGGGAT AATAGTCATT  
 181 TAAGTGTGTTT AAAAAATTAA TTTCAAGAAAT TTGTAAATGGA TACAAATGAAT ACAGAAAAAA  
 241 ATTAATGTTT AAAATCAAGC ACTAAATGAT TTTGTAAATGG CACTTTAGCT GGGGTATAT  
 301 GAAGTAAATT CTTAATGTGT AGAAAATCAA ACCTAACTCG ACAGTTCCCG TTTAAATTA  
 361 CCGTGTCTGT CAGATTAATT TGAGCTTAAA TCTCTTCTG CCCAAATCCG TTTCCATCA  
 421 AGTAATGTTG CCATCGGTGT TCTGCCACAG CACACTTTTC CTTGATGTGT TCGATGGTGA  
 481 TTATAATACA TAAACCACTC ATCTAAATCA GCTTGTAAATG TCGCTAAATC CGTATATATT  
 541 TTCTTCCTAA ATGCGACTTG GTAAAATTCT TGTAAGATAG TCTTATGAAA ACGTTCACAG  
 601 ATACCATTG TCTGTGGATG CTTCACTTTC GTTTAGTAT GCTCTATGTC ATTTATCGCT  
 661 AAAATAAGCT CATAATCGTG ATTTTCCACT TTGCCACAAAT ATTCACGTGCC ACGGTCGGTG  
 721 AGAATACGCA ACATCGGTAA TCCTTGGGCT TCAAAGAACG GCAGTACTTT ATCATTGAGC  
 781 ATATCTGCAG CGGCAATTG CCGTTTCATT GTGTAGAGCT TTGCAAAAGC AACCTTACTA  
 841 TAAGTATCAA CAAATGTTG CTGATAAAATG CGTCCAACAC CTTTAAATT ACCTACATAA  
 901 AAGGTATCTT GTGAACCTAA ATAGCCCCGA TGAGCGGTTT CAAATTCTCC ACTCGATATA  
 961 TCATCCTCTT TCTTACGTTTC TAGGGCTTGG ACTTGACTTT CATTAGAAT AATGCCCTTC  
 1021 TCAGCCACTT CTTTCTCTAG TGCAATTAAA CGCTGTAAAGTGTAGTAAAG ATTATGACGT  
 1081 AGCCAAATGG AACGAACACC ACCGGCTGAA ACACACACAC CTTGCTTGCG AAGTCGTTA  
 1141 CTCACTCGAA CTTGTCCGTA AGCTGGAAAA TCTAGAGCAA ATTTACAAAC AGCTGCTCA  
 1201 ATGTGCTCGT CTACTCGATT TTTGATATTG GGTACCCGAC GAGTTTGCTT AACTAATGCT  
 1261 TCAACACCGC CTTGCGCTAC GGCTTGTGAA TAGCGATAGA ATGTATCTCG GCTCATTCCC  
 1321 ATCGCTTAC AAGCTTGAGA AATGTTCCG AGTTCTCTG CTTAAATTGAG TAAACCGGTC  
 1381 TTGTGTTAA TGAGCGGATT GTTAAATAA AACATGAGAG TTTCTTTT TGTTAGATT  
 start of open reading frame <---- MET SD  
 1441 GAATTTAGA CACTCATATT CTAAACGGGA AACCTCTCATT TTTATAATGA TTTGTCAGAT  
 1501 CAAAGTCTGAT CTTCTACAAA TATTATCCCC ATTTATGGAG TTGCTCTTT AGATGAACTC  
 inverted repeat  
 1561 CTATTGTTA TAATTCGATA AAAATTAGCTT TCTCACAGCA ACTCAGCAAT GGGTTGCTTT  
 1621 TTTATTGAC AGAAAAACAA CGTAGATCT  
 S. 111

FIGURE 16

## INTERNATIONAL SEARCH REPORT

International Application No.

PCT/CA 92/00460

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate)										
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 C12N15/31; A61K39/102; C12N1/21; C07K13/00 //(C12N1/21, C12R1:19)										
II. FIELDS SEARCHED										
<table border="1"> <thead> <tr> <th colspan="3">Minimum Documentation Searched<sup>9</sup></th> </tr> <tr> <th>Classification System</th> <th colspan="2">Classification Symbols</th> </tr> </thead> <tbody> <tr> <td>Int.Cl. 5</td> <td>C07K ;</td> <td>C12N ; A61K</td> </tr> </tbody> </table>		Minimum Documentation Searched <sup>9</sup>			Classification System	Classification Symbols		Int.Cl. 5	C07K ;	C12N ; A61K
Minimum Documentation Searched <sup>9</sup>										
Classification System	Classification Symbols									
Int.Cl. 5	C07K ;	C12N ; A61K								
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>										
III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>10</sup>										
Category <sup>11</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>								
X	WO,A,9 106 653 (THE TEXAS A&M UNIVERSITY SYSTEM) 16 May 1991  see figure 1	1,8-9, 15, 27-28, 32-34 12								
X	DNA vol. 8, no. 9, November 1989, NEW YORK, USA pages 635 - 647 CHANG, Y.-F. ET AL. 'Cloning and characterization of a hemolysin gene from Actinobacillus (Haemophilus) pleuropneumoniae' cited in the application see the whole document	27-28, 32-33								
		-/-								
<p><sup>10</sup> Special categories of cited documents :      "A" document defining the general state of the art which is not considered to be of particular relevance      "E" earlier document but published on or after the international filing date      "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)      "O" document referring to an oral disclosure, use, exhibition or other means      "P" document published prior to the international filing date but later than the priority date claimed</p> <p><sup>11</sup> T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention      "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step      "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art      "R" document member of the same patent family</p>										
IV. CERTIFICATION										
Date of the Actual Completion of the International Search 07 JANUARY 1993	Date of Mailing of this International Search Report 22.01.93									
International Searching Authority EUROPEAN PATENT OFFICE	Signature of Authorized Officer ANDRES S.M.									

III. DOCUMENTS CONSIDERED TO BE RELEVANT		(CONTINUED FROM THE SECOND SHEET)	
Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.	
X	WO,A,9 012 591 (UNIVERSITY TECHNOLOGIES INTERNATIONAL INC.) 1 November 1990		1-2,15, 34
Y	see the whole document		12 1-7, 35-37
X	EP,A,0 420 743 (RHÔNE MERIEUX) 3 April 1991		1,8,15
	see the whole document		---
X	INFECTION AND IMMUNITY vol. 59, no. 9, September 1991, WASHINGTON US pages 3026 - 3032 FREY, J. ET AL. 'Nucleotide sequence of the hemolysin I gene from <i>Actinobacillus</i> <i>pleuropneumoniae</i> ' cited in the application see the whole document		27,32-33
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P,X	INFECTION AND IMMUNITY vol. 60, no. 8, August 1992, WASHINGTON US pages 3253 - 3261 GERLACH, G.-F. ET AL. 'Characterization of two genes encoding distinct transferrin-binding proteins in different <i>Actinobacillus pleuropneumoniae</i> isolates' see the whole document		16-18, 23-26, 32-33, 35,37
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P,X	INFECTION AND IMMUNITY vol. 60, no. 3, March 1992, WASHINGTON US pages 892 - 898 GERLACH, G.-F. ET AL. 'Cloning and expression of a transferrin-binding protein from <i>Actinobacillus</i> <i>pleuropneumoniae</i> ' see the whole document		16-17, 23-24, 32-33,35
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P,X	VACCINE vol. 10, no. 8, 1992, GUILDFORD GB pages 512 - 518 ROSSI-CAMPOS, A. ET AL. 'Immunization of pigs against <i>Actinobacillus</i> <i>pleuropneumoniae</i> with two recombinant protein preparations' see the whole document		1-4,8-9, 13, 15-17, 23-24, 27-28, 32-34
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			-/-

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
P,X	<p>INFECTION AND IMMUNITY vol. 59, no. 11, November 1991, WASHINGTON US pages 4110 - 4116 ANDERSON, C. ET AL. 'Isolation and molecular characterization of spontaneously occurring cytolysin-negative mutants of <i>Actinobacillus pleuropneumoniae</i> serotype 7' see the whole document</p> <p>-----</p>	27-28, 32-33

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/CA92/00460

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:  
Remark: Although claim 34 is directed to a method of treatment of the human/animal body the search has been carried out and based on the alleged effects of the compound/composition.
2.  Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3.  Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.  
 No protest accompanied the payment of additional search fees.

ANNER TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. CA 9200460  
SA 65461

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 07/01/93

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9106653	16-05-91	AU-A-	6751390	31-05-91
		EP-A-	0500736	02-09-92
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WO-A-9012591	01-11-90	AU-A-	5526190	16-11-90
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EP-A-0420743	03-04-91	FR-A-	2652266	29-03-91
		AU-A-	6523090	28-04-91
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